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# THE GEOLOGY AND MINERALOGY OF A TERTIARY BURIED PLACER DEPOSIT, SOUTHERN BRITISH COLUMBIA

by

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A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled ..The Geology and...... Mineralogy of a Tertiary Buried Placer Deposit, Southern.. British Columbia................................................ submitted by ....Alan James Aubut.......................... in partial fulfilment of the requiremtns for the degree of Master of ..Science........................

## ABSTRACT

The Swan Prospect, operated by Cal-West Petroleums Limited of Calgary, consists of an underground mining operation, used to extract native gold and Platinum Group Elements from the gravels of a buried placer deposit. This placer deposit consists of a Tertiary (?) channel, containing Au-Pt bearing gravels, which become inundated and preserved by Pleistocene fluvial-glacial sands and gravels.

The channel, as exposed in an old hydraulic pit and by underground workings, occupies a narrow, canyon-like structure cutting through argillites and volcaniclastic sediments of the upper-Triassic Nicola Group. The channel shows evidence of being strongly controlled by the pervasive joint system of the area and by the presence of a number of narrow quartz diabase and vogesite dykes. The channel is filled with an unknown thickness of well cemented sandy gravel with the binding agent being smectite clays. This gravel is poorly sorted with some stratification visible in cross-section. It consists predominantly of rounded to subangular fragments of allochthonous volcanic, sedimentary and intrusive material with abundant quartz and feldspar in the finer portions. Also present are abundant angular autochthonous fragments of argillite and volcaniclastic sediments. Based on several parameters, in particular clay-silt content, it is classified as transitory between a bed-load and a mixed-load channel.

These gravels have been mined by drifting along the base of the channel. This method has now been dropped in favour of sub-level stoping. The gravels are removed by tracked vehicles to the washing plant. This

plant, on Granite Creek, consists of an enclosed sluice box fed by a grizzly and hopper unit. Periodically the concentrate is removed and hand-panned.

The gold present in the final concentrate is well-flattened with a mean Cory factor 0.195. Fineness is variable from grain to grain with a mean of 903.0 $\pm$ 26.3 $^{o}/oo$. This is in marked contrast to the gold removed from the modern placers of Granite Creek, and the Tulameen River, where the gold is more angular with a mean fineness of 889.5 $^{o}/oo$. This would tend to indicate that the Swan Prospect buried placer represents a deposit produced from a much reworked, mature, pre-existing placer deposit. The modern placers on the other hand are the product of primary erosion, and subsequent deposition, of auriferous lode deposits. This conclusion is further substantiated by the fact that the gravels of the buried channel are poorly sorted with no evidence of being reworked. Further more, there is evidence that the gold is not concentrated near the base of the channel as would be expected in a mature deposit.

Found with the gold are, generally ellipsoidal, smooth but pitted nuggets of PGE. These consist of a complex mixture of platinoid alloys and minerals. The dominant alloys are Pt-Fe alloy, platiniridium and tulameenite. Also present, as inclusions within the dominant alloys, are osmiridium, laurite, iridosmine, (Ir, Rh) Sb,S, $PtAu_4Cu_5$, RhSb and several platinoid minerals rich in Rh and Ir that are analogous to the Pd-Pt mineral Braggite. Non-platinoid mineral inclusions present are chromite, magnetite and minor pyrrhotite and chalcocite. Of special note is that (Ir,Rh) SbS, $PtAu_4Cu_5$, RhSb and the pseudo-braggite sulphosalts are minerals and alloys apparently unique to the area and are unnamed.

betrayed by its surface expression which can be accentuated through the use of stereographic aerial photographs. Photographic interpretation has shown the presence of several slope changes that may be related to underlying bedrock features such as the faces of old waterfalls. A widening of this pass may denote a broadening of the paleochannel analogous to an alluvial fan. This particular method, for observing topographic features, is potentially an invaluable tool that may lead to the discovery of other such paleochannels in the area.

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# CHAPTER ONE

# INTRODUCTION

## 1.1 INTRODUCTION

The Swan Prospect of Cal-West Petroleum Limited is based upon a Tertiary (?) paleochannel. This channel cuts through volcaniclastic and flysch-type sediments belonging to the upper-Triassic Nicola Group. During Pleistocene times, the channel was inundated by stratified fluvial-glacial deposits thus preserving the auriferous and platiniferous gravels in the ancient stream bed.

Utilizing aerial photographs, field observations, refraction seismic survey records and details of the channel as exposed by old and present workings, an attempt has been made to document this deposit. Included is a detailed resumé of the country rock geology, based upon the pertinent literature, and a detailed study of the mineralogy of the precious metals presently being extracted.

The deposit consists of fluvial gravels composed of autochthonous slates and greywackes and allocthonous materials, including fragments of the nearby Tulameen ultramafic complex. Heavy mineral concentrates obtained after sluicing of these gravels are composed of two main components. These are magnetite and chromite. Other heavy minerals found are gold, PGE*, garnet, zircon, ilmenite, plus minor native silver and copper. The gold is present as coarse, well-flattened nuggets (some having associated white quartz). The PGE

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*Platinum Group Elements - this term indicates the chemical complexity of the platinoid nuggets found in the deposit and will be used throughout in this context.

nuggets, a complex association of platinoid alloys and minerals, occur as small, rounded grains of relatively uniform size. Many of these nuggets have a smooth, pitted surface commonly having adhering grains of chromite, magnetite and occasionally of olivine and pyroxene.

A number of PGE-bearing placer deposits, most with associated gold, are known throughout the world. The only such placers of economic importance today are those found in Columbia (S. America), Alaska (the Goodnews Bay deposit), the USSR (the Ural Mountains deposits) and the Republic of South Africa (Witwatersrand deposits). These probably account for about 3% of the world's PGE production (Butterman, 1975). Those deposits found in the Americas and the USSR are associated with zoned, chromite-rich, "alpine-type" ultra-mafic intrusions, typically with a central core of dunite (Stanton, 1972). The PGE metals, which occur as alloys, discrete minerals and as solid-solutions in the lattices of forsterite and spinels, are concentrated in chromitite zones. Though economic concentrations of the PGE are not present in these "alpine-type" intrusions, economic concentrations can be produced by weathering and subsequent placer accumulation. Such placers are characterized by the nearly complete absence of Pd and by the common presence of Au (Butterman, 1975).

The property is located 16 km west of Princeton, British Columbia, and 1 km southeast of the small village of Coalmont (see Fig. 1-1). The paleochannel lies within a southeast-northwest striking saddle originating approximately 1.5 km upstream of the present mouth of Granite Creek. Variations in the topography within this gap through the hills betray the approximate position of the buried stream course.

# Location Map

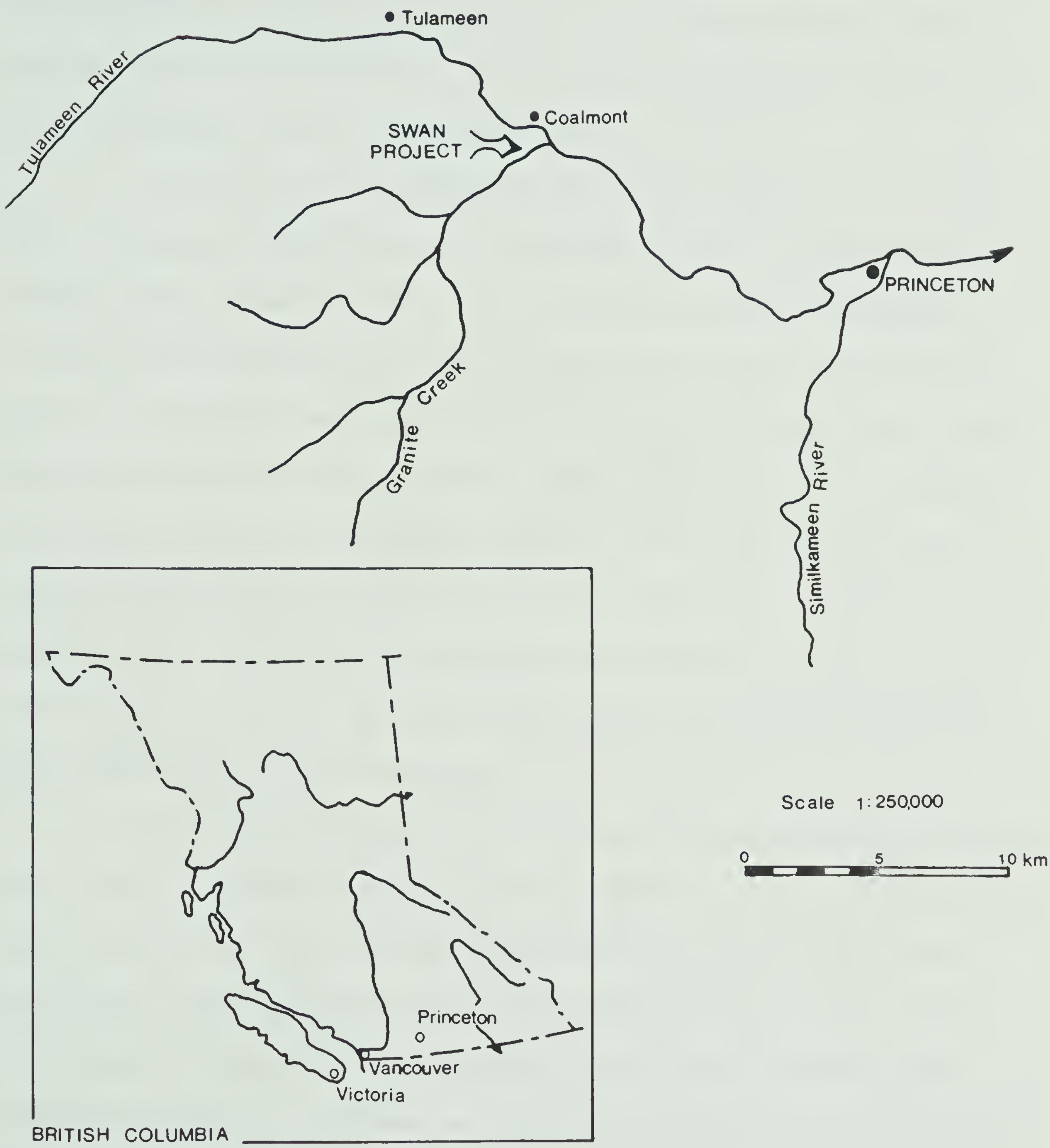



FIG. 1-1

## 1.2 HISTORY

Gold was first noted in the Princeton area in 1853 when G. B. McClellan discovered traces in the gravels of the Similkameen River. By 1860 placer-mining was being carried out on a regular basis. With the discovery of gold in the Cariboo district that same year, the resultant gold rush lured most, if not all, of the miners away, leaving the river valley deserted (Galloway, 1931).

It was not until 1885 that interest in the area was renewed when John Chance discovered gold in Granite Creek, a tributary of the Tulameen River (Camsell, 1913). By the end of October of that year a total of 65 companies had staked claims on the lower portion of the creek. One of these was called the SWAN claim (Galloway, 1931). Since the season was well advanced at this time production did not actually get underway until the following spring. During this first year of activity approximately 10,575 oz.of gold was extracted from the gravels. Also discovered with the gold was platinum. Initially its value was not realized; the metal being either sold for 50¢ an oz. or simply being discarded as worthless.

As the more easily worked stream gravels became played out, interest slowly shifted to the many bench deposits found along the stream banks. As work on these benches progressed it became evident that a pay streak, representing an earlier, and higher level, stream course was present. By 1898 the only important operations involved either drifting on these old channels or preparing for hydraulicing (Galloway, 1931).

In 1902 the Granite Creek Hydraulic Company began hydraulic operations on a portion of an old channel that appeared to follow a

draw through the surrounding hills, on the SWAN claim. This channel was then exposed for about 50 m with it continuing, under the local mantle of fill, apparently through the draw to the Tulameen River, approximately 1 km upstream of the present mouth of Granite Creek. Also at this time the Boston and B.C. Mining Company was operating a washing plant where this channel was thought to enter the Tulameen River. Its existence was betrayed by bedrock outcrops on either side of the presumed channel. The company, in order to define this channel sank a 25 m deep shaft, but failed to hit bedrock (B.C. Dept. of Mines Annual Report, 1902). Both operations apparently were short lived.

After this initial activity the SWAN property was periodically reopened during the subsequent thirty or so years. Work was carried out for a short time, first in 1915 by Kane and Jamieson of Seattle, then again in 1923 by unknown American interests (B.C. Dept. of Mines Annual Report, 1915; 1923). In 1925 the Hematite Iron and Gold Mines Development Company began an ambitious program of underground exploration. An adit was driven 107 m NW and then from this an 18 m deep shaft was sunk. These workings helped define a narrow, steep-walled canyon about 20 m wide and striking NE. A new adit was then started from the Tulameen River side, near Coalmont, with the intention of drifting the 1.2 km SW to the SWAN claim (B.C. Dept. of Mines Annual Report, 1925). Soon after all work was abandoned. The SWAN property was reopened a fourth time in 1934 by International Placers Limited. A total of 80 m of drifting was carried out in the auriferous gravels yielding 173 oz. of gold and 18 oz. of platinum. This company also carried out some churn drilling at the Tulameen River end of the channel in an attempt to pinpoint the channel's

actual location (B.C. Dept. of Mines Annual Report, 1934).

Over the next twenty-six years the channel received no further attention until, in 1960, the Geojimal Mining and Development Company reopened the SWAN claim (now Placer Mining Lease #1333). A total of 106 m of drifting in bedrock was carried out. The following year an additional 62 m of drifting, including the construction of three 12 m raises, was also carried out. In all cases, when the channel was broken into, by raising, only old workings were encountered (Timmins, 1976, internal company report).

Harkor Developments Limited (which has since been absorbed into Cal-West Petroleum Limited) reopened the property in 1974 and further underground development work was initiated. This resulted in a further 200 m of drifts, three raises totaling 37 m and 50 m of subdrifts, within the channel gravels, being constructed. This, plus the previous development work of Geojimal Mining and Development Company constitutes the present extent of the underground workings. During 1977 previously unworked channel gravels were broken into. By sub-drifting within the channel the auriferous gravels were extracted then passed through a grizzly and sluice box in order to remove the heavy minerals. Due to financial difficulties Cal-West Petroleum has since shut down the operation for an indefinite period.

## 1.3 PREVIOUS GEOLOGICAL WORK

G.M. Dawson (1887b) was the first to visit and make geological observations on the gold-platinum placers of the Tulameen district. He was followed, in 1900, by J.F. Kemp (1902) who spent three months studying the platinum resources of the area. Camsell (1913), over a

two year period, examined the geology and the mineral deposits of the district. E. Poitevin (1923) investigated the ultrabasic Tulameen Complex to see if any similarities existed between it and the platiniferous ultrabasic intrusions found in the Urals of Russia. The last complete account of the area was given by Rice (1947). Since then Findlay (1963) has studied the petrography of the Tulameen Complex and Schau (1968) has made a detailed study of the Nicola Group.

# CHAPTER TWO

# REGIONAL GEOLOGY

## 2.1 INTRODUCTION

The geology of the Granite Creek area is illustrated in Fig. 2-1. The area is underlain by a succession of volcanic rocks, interbedded sedimentary rocks and by felsic to ultrabasic intrusive rocks. These all range in age from early Mesozoic to Tertiary. The ages and field relationships of these rock units are, in many cases, obscure (Rice, 1947). A table of formations, for the area of Fig. 2-1 is presented in Table I.

With regard to the Swan prospect gold-platinum placer deposit the two stratigraphic entities of most importance are the Tulameen Complex and the Nicola Group. The former is especially important since it is known to be platiniferous and is generally accepted as the source of the platinoid grains found in the deposit. The Nicola Group, besides constituting the underlying bedrock for the deposit, is also the probable source of the gold. Because of their relative importance they are fully described in Sections 2.2 and 2.3.

## 2.2 TULAMEEN COMPLEX

The Tulameen Complex is a concentrically zoned, Alaskan-type ultramafic body (Jackson and Thayer, 1972; Naldrett and Cabri, 1976). It consists of a central dunite core rimmed successively by pyroxenites and gabbroic rocks. The complex is an elongated body with an exposed area of 57 $km^2$. It intrudes rocks of the late-Triassic Nicola Group (see Fig. 2-2).

Table I

Table of Formations

| ERA | PERIOD OR EPOCH | GROUP OR FORMATION | LITHOLOGY |
|---|---|---|---|
| CENOZOIC | Pleistocene and recent | | Glacial till; silt, sand and gravel |
| | UNCONFORMABLE CONTACT | | |
| | Miocene or later | Plateau basalt | Mainly amygdalodal basalt |
| | UNCONFORMABLE CONTACT | | |
| | Miocene or earlier | Princeton Group | Mainly basalt, andesite, fossiliferous shake, sandstone and conglomerate |
| UNCONFORMABLE CONTACT | | | |
| MESOZOIC OR CENOZOIC | Upper Cretaceous or later | Otter Intrusions | Mainly pink granite and granodiorite with some porphyritic grey granodiorite. |
| INTRUSIVE CONTACT | | | |
| MESOZOIC | Lower Cretaceous | Kingsvale Group | Agglomerate, greywacke, volcanic breccia, andesite and basalt with orange-coloured feldspar phenocrysts. |
| | | Relations not known, but apparently of same age | |
| | | Pasayten Group | Greywacke, fossiliferous argillite, sandstone and conglomerate with a conspiceous horizon of purple tuff and lava. |
| | | Unconformable or disconformable with Kingsvale; not in contact with Pasayten | |
| | | Spence Bridge Group | Red, purple, buff and grey rhyolite, dacite and basalt. |
| | Not in contact with any of the above except Princeton Group, which overlies it unconformably | | |
| | Jurassic or Later | Copper Mountain Intrusions | Primarily pink to red syenogabbro, augite diorite and pegmatite. |
| | | NOT IN CONTACT | |
| | | Coast Intrusions | Grey, red and white granodiorite (from oldest to youngest respectively) |
| | | Intrusive contact in places, but in others possibly gradational | |
| | | Tulameen Complex | Coarse grained pyroxenite, gabbro and peridotite |
| | INTRUSIVE CONTACT | | |
| | Upper Triassic | Nicola Group | Mainly augite or feldspar phyric andesite with many beds of tuff, tuffaceous argillite and argillite with some occational lenses of linestone. |

(Adapted from Rice, 1947)

Figure 2-1

Legend

TERTIARY

Miocene or Later

10 Plateau Basalt

Miocene or Earlier

9 Princeton Group

(a) mainly shale, sandstone, and conglomerate; coal.

(b) varicoloured andesite and basalt.

CRETACEOUS OR TERTIARY

Upper Cretaceous or Later

8 Otter Intrusions: pink and grey granite and granodiorite.

CRETACEOUS

Lower Cretaceous

7 Kingsvale Group: mainly volcanic breccia

6 Pasayten Group: mainly grit and shale

5 Spence Bridge Group: hard, reddish andesite and basalt.

JURASSIC OR LATER

4 Copper Mountain Intrusions: syenogabbro, augite diorite, and pegmatite

3 Coast Intrusions: grey, red and white granodiorite.

2 Peridotite, Pyroxenite, Gabbro (for detailed geology of the Tulameen Complex see Fig. 2-2).

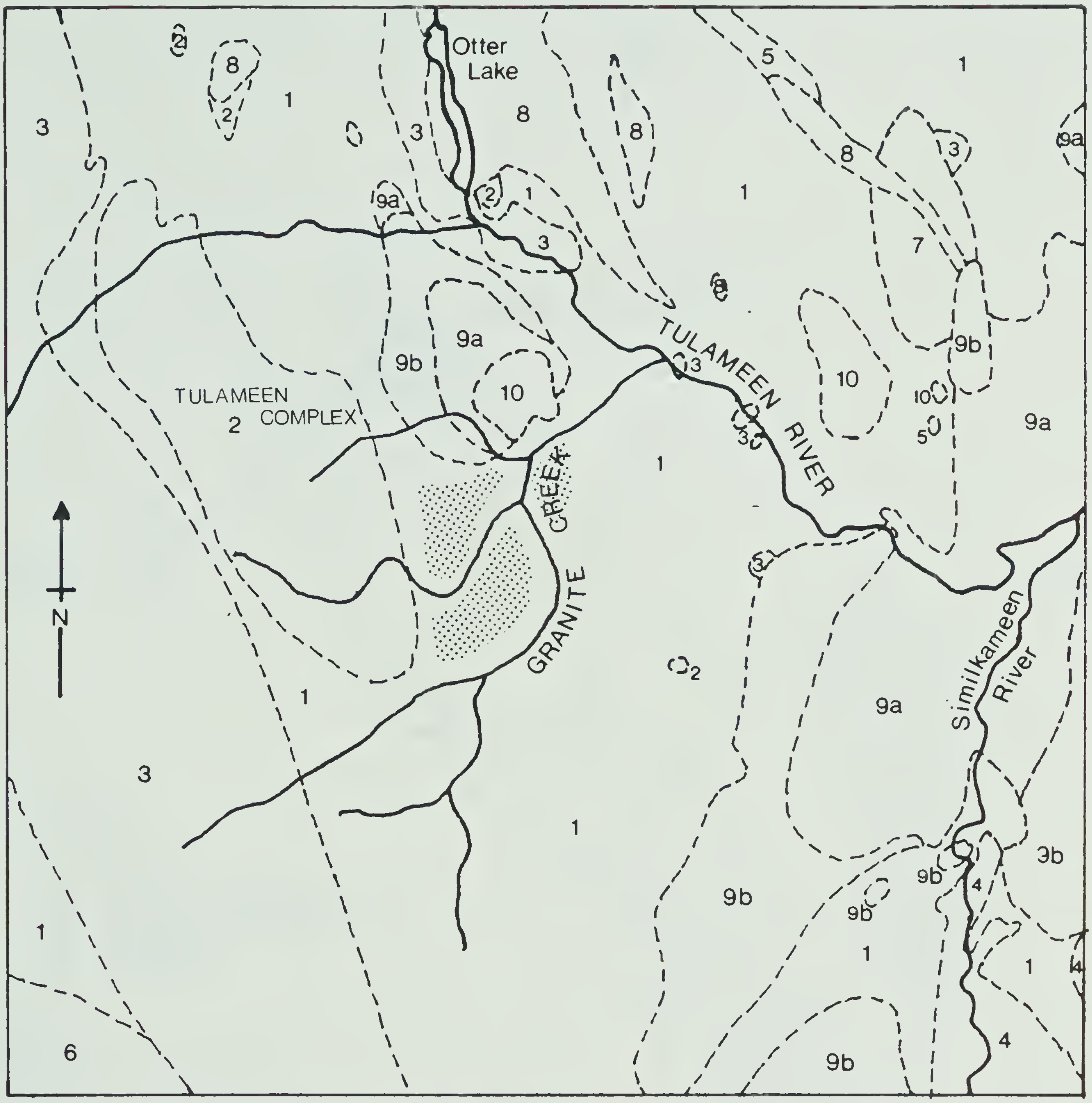
TRIASSIC

Upper Triassic

1 Nicola Group: varicoloured lava; argillite, tuff, limestone; chlorite and sericite shist.

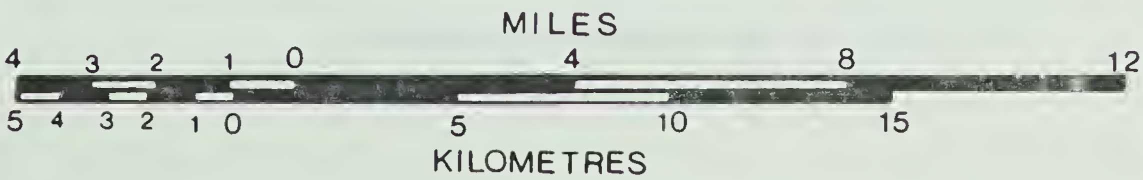
Adapted from Rice (1947).

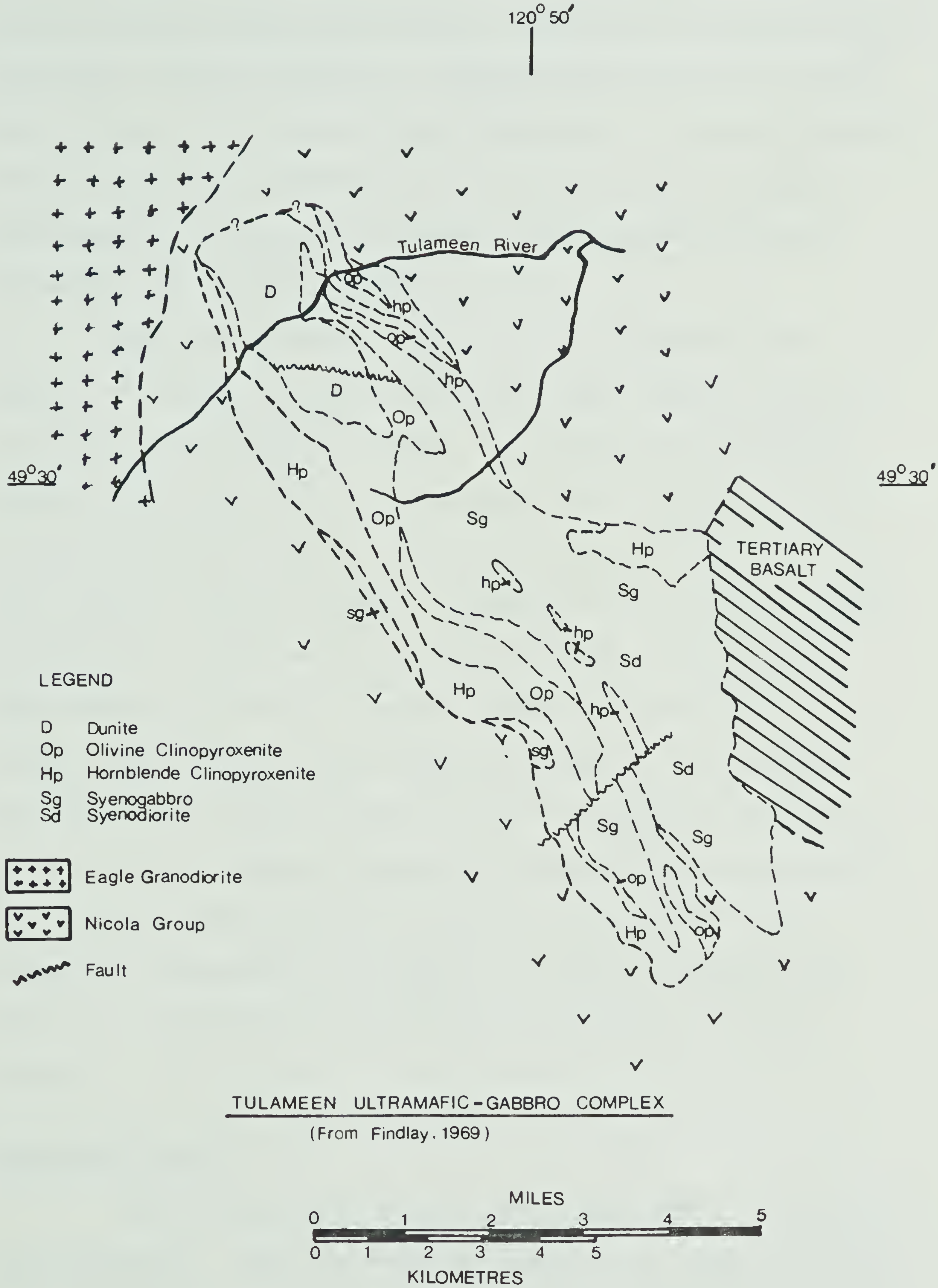
areas in which other paleoplacers may be found.




GEOLOGY OF THE GRANITE CREEK AREA
( Adapted from Rice, 1947 )

**Fig. 2-1**






TULAMEEN ULTRAMAFIC-GABBRO COMPLEX

(From Findlay, 1969)

FIG. 2-2

The complex possesses an inner ultramafic suite and an outer, stratigraphically higher, mafic suite. Both suites are undersaturated. The gabbroic rocks are alkalic in character and so may not be genetically related to the ultramafic rocks but rather to a regional alkaline intrusive suite that includes the Copper Mountain stock. Based on this evidence, it is believed that both suites represent discrete intrusive events (Findlay, 1963).

Kemp (1902), in his study of the platiniferous placer deposits of the area, concluded that the Tulameen Complex represents the source of the platinoid minerals. He noted that the platinum-bearing gravels were found only downstream of the complex and as it was approached the proportion of platinoid metals to that of gold in these placers, increased notably. Furthermore, the platinoid nuggets are intimately associated with grains of chromite and occasionally with olivine and pyroxene. Chemical analyses by Kemp (1902) and Camsell (1913) indicated that samples of peridotite and pyroxenite from the Tulameen Complex commonly contained platinum in amounts up to 2 oz. per ton. The best results were obtained from the peridotite with serpentinized peridotite and chromitite being particularly anomolous. Unfortunately the platinum is unevenly distributed and generally in quantities too low to make lode mining, at present, economic.

### The Gabbroic Suite

There are two main gabbroic rock types present: syenogabbro and syenodiorite. Both have potassium feldspar as a major constituent. These two rock types exhibit a crude zoning with syenodiorite generally

being restricted to the interior part of the body whereas the syenogabbro is prevelent around the margins. The major primary constituents are potassium feldspar, plagioclase and clinopyroxene. Hornblende is common as an alteration product of the clinopyroxene. The syenogabbro is differenciated from the syenodiorite by having a higher proportion of clinopyroxene and hornblende (30 - 50% for syenogabbro versus 15 - 25% for syenodiorite) (Findlay, 1963).

(a) Syenogabbro

The syenogabbro is a massive to equigranular, mottled black and white rock. It is fine- to medium grained and is composed of dark green or black diopsidic augite (35 - 50%), white andesine feldspar (25 - 35%), orthoclase and, to a lesser extent, microcline (15 - 20% combined). The feldspars commonly show moderate to intense sausseritization. Accessory minerals are biotite (<4%), apatite and sphene (op. cit.).

(b) Syenodiorite

As with the other members of the gabbroic suite this rock type is usually altered. It is lighter coloured than the syenogabbro. The principal minerals present are hornblende, andesine, orthoclase and some microcline. Biotite is present locally. Apatite and magnetite (1 - 2%) are common. Clinopyroxene can usually be found as small remnant grains within the cores of hornblende crystals (op. cit.).

(c) Gabbro

Gabbro is very limited in extent, being restricted to zones

near, or within, ultramafic rocks. Alteration is ubiquitous with pyroxene commonly being replaced by hornblende, actinolite, and epidote. Biotite and chlorite are conspicuous in their presence. Potassium feldspar and magnetite are only present in minor amounts. The plagioclase is a more calcic andesine than that found in the other gabbroic rocks (op. cit.).

<u>The Ultramafic Suite</u>

There are three major units and five minor units comprising this suite. The major rock types are dunite, olivine pyroxenite and hornblende pyroxenite. The five minor rock types are peridotite, hornblende-olivine pyroxenite, clinopyroxenite, hornblendite and basic pegmatoids. The major units are megascopically distinctive, whereas the minor units are irregular and discontinuous and so are not easily defined. The characteristic distribution pattern exhibited by this suite is a central core of dunite enclosed by successive zones of more pyroxene - (olivine pyroxenite) and hornblende - rich (hornblende pyroxenite) members (op. cit.).

(a) Dunite

This rock is pale grey to greenish grey, and is fine- to medium-grained. It consists of mosaic-packed olivine ($Fo_{86-93}$) with accessory chromite and, rarely, widely-scattered grains of green clinopyroxene. Serpentine is common throughout, but is more abundant around the margins of this central core. The chromite, present as small (<0.5 mm), subhedral grains occurs commonly as widely scattered, discrete grains, but also as irregularly distributed pods and lenses varing between several millimetres to about 30 cm in size (Findlay,

1963). Commonly associated with these chromite concentrations are small quantities of platinum and minor gold (Camsell, 1913; Rice, 1947).

(b) Peridotite

Peridotite is found occasionally as small local zones along the dunite-olivine pyroxenite contact. On a fresh surface it is a mottled green and black, resulting from patches of dark-coloured olivine and serpentine, and grass-green areas of clinopyroxene. The olivine ($Fo_{81-91}$) and the clinopyroxene (diopside) are present in roughly equal proportions (Findlay, 1963).

(c) Olivine Pyroxenite

This, the second dominant ultramafic unit, consists primarily of diopsidic clinopyroxene (70 - 80%) and partly serpentinized olivine (10 - 20%). The rock typically has a green and black "blotchy" appearance. Another variety is green to greenish grey and lacks the blotchy appearance. Both are fine- to medium-grained, massive and equigranular. The olivine is distinctly more fayalitic ($Fo_{80-88}$) than that in the dunite. Magnetite banding is present in a few localities. These layers are between 6 and 13 mm thick and possess a distinct planar orientation that approximates the dip of the ultramafic contacts in that area (op. cit.).

(d) Hornblende-Olivine Pyroxenite

This rock unit, a minor variant of the olivine pyroxenite, is fairly restricted in areal distribution. It occurs as an intermediate type between olivine pyroxenite and hornblende pyroxenite. It

is composed of diopsidic clinopyroxene, hornblende, serpentinized olivine and accessory magnetite. Large, irregular plates of hornblende (up to 1 cm across) poikilitically enclose or partially surround subhedral, sub-equant prismatic crystals ($\leq$ 4 mm long) of clinopyroxene. The same is true when olivine is present (op. cit.).

(e) Clinopyroxenite

Clinopyroxenite does not form a distinctive field unit but rather is erratic in its distribution. It is generally monomineralic, though locally olivine is present up to 8 - 9% and magnetite varies up to 10 - 20%. It was subdivided into two types by Findlay (1963); olivine-bearing clinopyroxenite and hornblende-bearing clinopyroxenite. The former is a pale green, fine- to medium-grained rock consisting of diopside, partially serpentinized olivine (<10%) and accessory magnetite (<5%). The latter type differs only from hornblende pyroxenite in that hornblende is <5%. This rock type is massive and is fine- to medium-grained (op. cit.).

(f) Hornblende Pyroxenite

Of the ultramafic rock units present, this is the most extensive (approximately 51%). It occupies a position peripheral or marginal to the other ultramafics. It is fine- to coarse-grained consisting of diopside (30 - 75%), hornblende (5 - 70%) and magnetite (10 - 25%). Accessory minerals are apatite, biotite, and rarely sphene. The magnetite occurs as disseminated grains and as small irregular lenses and clots similar to chromite in the dunite (op. cit.).

The hornblende pyroxenite is generally massive with a local, crude, foliation due to a rough orientation of the tabular hornblende

crystals. The plates of hornblende are poikilitic in subhedral to anhedral diopside grains. When present in lesser amounts it is interstitial to the pyroxene (op. cit.).

(g) Hornblendite

Hornblendite constitutes a local variant of the hornblende pyroxenite that is commonly found in the marginal areas of the pyroxenite unit. It is a greenish black to black rock composed primarily of hornblende (>70%) with diopside and accessory magnetite. It varies from medium- to coarse-grained with local pegmatitic zones. The magnetite content is usually much less than in hornblende pyroxenite. Clinozoisite is locally present in minor quantities (op. cit.).

(h) Basic Pegmatoid

This rock unit is found only in a few localities, and usually consists of hornblendite. It is coarse-grained to pegmatitic, consisting of black hornblende and white to creamy, angular, interstitial plagioclase (usually saussuritised). It commonly occurs as irregular patches or lenses. Magnetite and apatite commonly occur as accessory constituents (op. cit.).

## 2.3 THE NICOLA GROUP

Rocks of the Upper Triassic Nicola Group are found in an area that extends 190 km southward from Kamloops Lake to the International Boundary and is up to 72 km wide. Preto (1977) has found this belt to consist of three north-south striking blocks separated by major faults. As yet no suitable marker horizon has been recognized

and thus their relationship to one another is unknown. These blocks are covered to the north by Tertiary rocks and to the south are cut by the Similkameen batholith (Carr, 1962).

Due to geological complexity, the stratigraphy and thickness of the Nicola Group remains largely unknown. In general it consists of a succession of lavas with lenses of tuffaceous and argillaceous rocks with occasional limestone beds (Rice, 1947). There is a wide variety of volcanic types present, the most common of which is phyric-andesite with phenocrysts of pyroxene and/or plagioclase.

The Nicola Group exhibits vertical and lateral heterogeneity with most clastic units being lenticular in form. Siliceous tuffs form thin, widespread beds. Calcareous horizons, though persistant laterally, show marked variability, along strike. The andesites commonly exhibit flow layering.

A number of auriferous lode deposits have been found cutting the Nicola Group, primarily in the vicinity of the Tulameen Complex. These deposits occur as quartz veins and as breccia zones cemented by quartz. The veins consist of lenses varing from several centimetres to approximately two metres in width. The quartz is white and glassy with mineralization usually consisting of pyrite, minor chalcopyrite, rarely galena, sphalerite and hematite. The gold occurs generally in isolated pockets as free-milling native gold and as tellurides (Camsell, 1913; Rice, 1947).

These gold-bearing quartz veins are generally considered to be the source of the gold within the placer deposits. This is based in part on glassy to milky quartz grains occasionally being found still attached to some gold nuggets. Furthermore, all the important

placer deposits are located downstream of a number of known lode deposits. A case in point is Granite Creek where one lode deposit was mined economically for a short period around the turn of the century. This particular deposit, plus a number of other occurrences are located in the upper portions of the Granite Creek valley, above the sites of the auriferous gravels found in the lower reaches of the stream (Camsell, 1913).

The type section of the Nicola Group, on the south side of Nicola Lake, was first described by Dawson (1877a). Schau (1968) has carried out a detailed study of the Nicola Group in this area. He was able to differentiate two distinct cycles of volcanism and associated sedimentation.

Each cycle consists of a lower, predominantly volcanic assemblage (1), and an upper heterogenous, but mainly sedimentary, assemblage (2) (Schau, 1968). The volcanic assemblage of the lower cycle (P1), with a thickness of 1800 m, is composed primarily of altered feldspar-phyric flows of andesitic basalt and abundant, relatively coarse, pyroclastics. These flows, usually less than 30 m thick, vary from strongly porphyritic or glomeroporphyritic to completely aphanitic. The feldspars in the glomerophyric flows are equant commonly sausseritized, and up to 7 mm long. These are set in an aphanitic groundmass which varies in colour from greenish or bluish black, at the base of the pile, to black in the middle, to purple near the top. This matrix consists of opaques scattered through intersertal chlorite, albite microlites, and epidote grains. Clinopyroxene, usually completely altered to calcite, epidote and chlorite can occasionally be found (op. cit.).

Pyroclastics are prevalent in the upper half of the volcanic sequence. They consist mainly of angular fragments, up to 12 cm across, which vary from porphyritic, amgdaloidal, aphanitic and flow layered textures. These are set in a reddish matrix generally containing small lapilli. Many of these lapilli have red borders with dark red cores. Volcanic breccias found in this sequence have moderately sorted, porphyritic fragments, with few lapilli set in a sparse, fine-grained matrix (op. cit.).

Lapilli-bearing crystal tuffs and lithic tuffs are present throughout the sequence as interflow layers, but are particularly abundant near the top. The crystals are mainly broken feldspars, and the lithic fragments are the same as the previously described flows (op. cit.).

Occurring as isolated, intercalated lenses within the volcanics, are well-sorted arenites, fossiliferous greywackés, re-crystallized limestones and conglomerate. Occasionally blocks of limestone up to 12 m in length are caught up in the flows (op. cit.).

The 2400 m thick upper, primarily sedimentary assemblage (P2) of the lower cycle consists of basaltic andesite to andesite flows, agglomerates, breccias, tuffs, greywackes and carbonates. The feldspar-phyric flows resemble those of the lower assemblage (P1). Augite phenocrysts are also sometimes present. Near the top of this sequence are found andesite flows and dykes up to 14 m thick. These flows commonly have irregularly oriented flow layering near the top and prominent convex sheeting near their base. Interbedded with these are agglomerates and breccias of comparable composition. The matrix of these agglomerates is commonly red tuff consisting of large

albite crystals, uralite, fine-grained epidote, leucoxene and opaques with interstitial chlorite and quartz. Veins of quartz, epidote, chlorite and albite can be found cutting both fragments and matrix (op. cit.).

The breccias consist of volcanic fragments set in an amygdaloidal, hematitic, devitrified matrix. The fragments average about 10 cm long (op. cit.).

Lithic tuffs are common, with purple feldspathic and vitric tuffs also being present. A potential marker horizon present in this sequence consists of a bedded, quartzose, vitric tuff. Also present in this tuff are dacite fragments containing bipyramidal, partially resorbed, quartz phenocrysts and clots of altered feldspar, all set in a mozaic of quartz, albite, hematite, other opaques and sphene (Schau, 1968).

The greywackes are generally green in color with some being mauve or tan. The fragments are angular to subangular and consist of red and black aphanite and bright green chloritic glass fragments set in a medium- to fine-grained matrix. Occasionally benthonic fossils and carbonized twigs are encountered. The mauve volcanic wackes consist of calcite fragments, porphyritic scoria fragments, altered feldspar crystals, some subangular clinopyroxene grains and occasional quartz grains all set in a matrix of recrystallized calcite and chlorite. Medium-grained plagioclase wackes consist of plagioclase grains, now altered to albite, in a matrix of chlorite, albite, calcite and quartz (op. cit.).

The calcareous rocks are usually fossiliferous. They consist predominantly of reefal masses of, rarely vuggy, occasionally bitu-

minous, light grey limestone. Organic remnants present include crinoid columnals, spongiomorphs, coral debris, echinoid spines, pelecypod debris, algal mats and, rarely, bryozoans. Organ-pipe spongiomorphs have been partly preserved by secondary quartz. Some of the material is a poorly sorted fossiliferous rudite with a partly recrystallized micrite matrix (op. cit.).

The upper cycle (A) of the Nicola also consists of two assemblages. The lower assemblage (A1), with an approximate thickness of 2300 m, consists primarily of flows and pyroclastics characterized by a preponderance of pyroxene phenocrysts. These phyric flows are basaltic in composition and are amygdaloidal. The equant, euhedral pyroxene phenocrysts are up to 15 mm long. Some flows also contain small (up to 5 mm) tabular feldspar phenocrysts. One variety of flow, near the base of the assemblage, contains red blebs of hematite, probably pseudomorphic after olivine. The fine-grained matrix of the flows is generally green, though near the base it is grey to red (op. cit.).

The pyroxene phenocrysts are augite crystals, commonly exhibiting hourglass and oscillatory zoning. These are set in a matrix of epidote, sausseritized feldspar, albite, chlorite, calcite and, rarely, green biotite. Remnant zoned labradorite can occasionally be found in the sausseritized feldspar phenocrysts. Amygdules are filled with epidote, quartz, chlorite, calcite, potassium feldspar, pumpellyite, minor sulphides, albite and actinolite (op. cit.).

Both flow- and pyro-breccias are present. The fragments consist of vari-coloured basalt set in a matrix of similar material. One breccia found by Schau (1968) consists of partially rounded fragments, mainly of basalt but also including altered quartz diorite and

hornblende-bearing gabbro fragments. Also present in this breccia are very rare pebbles of hornblende-bearing volcanics. This breccia changes along strike into a cobble conglomerate with a partly calcareous matrix (op. cit.).

The agglomerates and lapilli tuffs commonly contain porphyritic fragments set in a hematitic-rich matrix resulting in a characteristic red colour. These altered pyroclastics are finer grained than those present in the upper, heterogenous assemblage. Also present are some lenses of altered crystal and lithic tuffs (op. cit.).

The volcanic wackes are red to green in colour, poorly sorted, medium-grained and have beds ranging up to 30 m thick. Ripple marks and infrequent cross-bedding can be found. Fragments include small pyroxene grains and less commonly feldspar grains (op. cit.).

Near the top of the assemblage are found lenticular bodies of limestone, associated with conglomerate. These limestones are grey in color and variably recrystallized. Locally irregular layers of green tuffaceous material or fragmentary fossil forms can be found (op. cit.).

The upper assemblage of the upper cycle (A2) is at least 490 m thick. It consists primarily of thick- and thin-bedded greywackes and argillites. Worm tracks, ripple marks, load casts, cross-bedding and other sedimentary structures are common. The wackes are grey to green in colour and consist of medium-grained, poorly-sorted pyroxene and feldspar grains. These grains are set in a fine-grained, rarely calcareous, matrix of similar material which has been altered to epidote, quartz, albite and chlorite. The argillites are light green to dark green or black and weather to a tan colour. They are composed

of albite, chlorite, quartz mosaics, minor relict pyroxene, epidote, pyrite and calcite (op. cit.).

## 2.4 GEOMORPHOLOGY AND SUMMARY OF GLACIAL HISTORY

The Tulameen River, and its tributaries, lie in the zone of demarcation between the Thompson Plateau and the northerly extention of the Cascade Mountains. This zone is nowhere sharp but rather constitutes a gradual transition between the plateau and mountain terrains. Within this transition zone typical plateau features are not well developed with the formation of a more rugged type of topography being more characteristic (Camsell, 1913).

The Thompson Plateau is characterized by topography indicative of mature erosion which has subsequently been transected by steep-walled valleys. In the southern portion of this north-south striking plateau, in the vicinity of Princeton, it is less than 160 km wide (Hills, 1962). Within this area two distinct drainage systems have developed. The predominant system consists of east-west trending, broad, U-shaped valleys, as characterized by the Tulameen River Valley and the lower Similkameen River Valley. The other system consists of north-south trending, deep, narrow, comparatively straight valleys such as those occupied by the tributaries of the Tulameen River (Rice, 1947).

Towards the SE and SW the plateau merges with several ranges of the Cascade Mountains. The Cascades bifurcate into two subsiduary ranges just north of the 49th parallel. One, the Okanagen Range, extends northeastwards into southern B.C. The other, which is further subdivided into two subordinate ranges, the Skagit and the Hozameen,

extends northward (Hills, 1962). It is the Hozameen Range that merges with the Thompson Plateau in the region of the headwaters of Granite Creek.

During the Pleistocene epoch this area was subjected to at least two glacial advances, the Okanagan Centre Glaciation and the Frazer Glaciation (Fulton, 1975). As a result the lower elevations below 2100 m are now characterized by rounded ridges and dome-shaped mountains (Holland, 1964). Both glacial advances were similar in areal development resulting in little being known of the first glacial period. The ice flow within the region was apparently towards the south and southeast, though flow features in many valleys diverge from this regional trend (Fulton, 1975).

Associated with the glacial advances was the extensive development of proglacial lakes (Fulton, 1975). Two such lakes, as indicated by several strand lines, were once present in the upper Tulameen River valley and the Granite Creek valley (Hills, 1962).

A melt-water channel, probably formed during retreat of the Fraser glaciation, is present along the southern flank of the present Tulameen River valley (see Plate V). This channel may have been cut during the third stage of retreat when the ice sheet was reduced to valley tongues, which were practically devoid of movement (Fulton, 1975).

A number of post-glacial features can be found in the area. These include river terraces, the occasional kettle hole and melt-water channels, all of which are modifications of the ubiquitous

mantle of fill that covers the area. Fabric studies on some terraced fill material, near Princeton show that it was derived from the north and from the Tulameen River to the West (Hills, 1962).

# CHAPTER THREE

# DESCRIPTION OF THE DEPOSIT

## 3.1 LOCAL GEOLOGY

The Swan prospect has to date been developed by drifting beneath and subdrifting within the gravels of the paleochannel. This channel cuts through country rock consisting entirely of Nicola Group flyschoid sediments. These sediments are further transected by a number of diabase dykes and by occasional lamprophyre dykes.

The sediments present in the study area consist primarily of steeply dipping dark green to black pyritic argillites characterized by a well-developed joint system (see Plate I). The argillites consist primarily of clay and detrital fragments, including quartz and pyroxene. Carbonaceous material is common throughout as an opaque dust, often accentuating the bedding within the rock. Cross-bedding, in lighter, more silty layers, is sometimes present.

Figure 3-1 presents a contoured stereogram of the conjugate joint system found within the study area. There are three primary joint sets with the dominant set having an average attitude of 116° - 78°S (A'). The two subordinate joint sets have approximate attitudes of 212° - 58 W (B') and 006° - 40°E (C'). The acute angle between A' and B' is 82°, between A' and C' is 87° and between B' and C' is 84°. In layered rocks, fabric-controlled pervasive fractures tend to be both parallel and perpendicular to the layering (Dennis, 1972). With regard to the study area it is not known whether such a relationship exists since the orientation of the bedding plane is not known. This is a result of the highly jointed nature and lack of good exposure of the sediments which mask bedding plane features.

Interbedded with the argillites are lithic and lapilli tuffs. The larger fragments within these tuffs consist primarily of andesite and devitrified glass. Minor quartz fragments are also present. All the fragments are set in a fine grained matrix of the same material with opaque dust commonly found rimming the fragments. Carbonate is usually present as secondary replacement of the fragments and matrix.

Several diabase dykes have been found cutting through the sediments. Usually they, and the surrounding argillites and tuffs have undergone accute alteration, resulting in ubiquitous sausseritization, chloritization and calcification. These dykes are medium-grained quartz diabase consisting of sausseritized plagioclase, chlorite and interstitial quartz. Occasionally unaltered or partly altered clinopyroxene is still evident.

Also present, cutting through the sediments, approximately 220 m NW of the mine portal, is a vogesite lamprophyre dyke. It consists of large (>1.4 cm) crystals of unaltered diopsidic clinopyroxene set in a fine-grained matrix of clinopyroxene, penninite and alkali feldspar. This massive dyke is about 1 m wide and has an apparent strike of 096°.

To the north of the mine site, along the south flank of the Tulameen River Valley, the argillites have apparently been strongly sheared, producing a well foliated, crenulated schist (Plate II). This very fine-grained rock consists primarily of sericite with strained quartz fragments, carbonate and minor pyrite also being present. This sericite schist has been found to outcrop on either side of the assumed mouth of the paleochannel.

Plate I

Typical Well-jointed Outcrop

Exposure of Nicola Argillite.

Plate II

Sericite Schist (right) That Shows

Folding. It is Intruded by a Massive

Quartz Diabase Dyke (left).

PLATE I

PLATE II

Figure 3-1

Stereographic Plot of Joint

Data From the Swan Prospect.

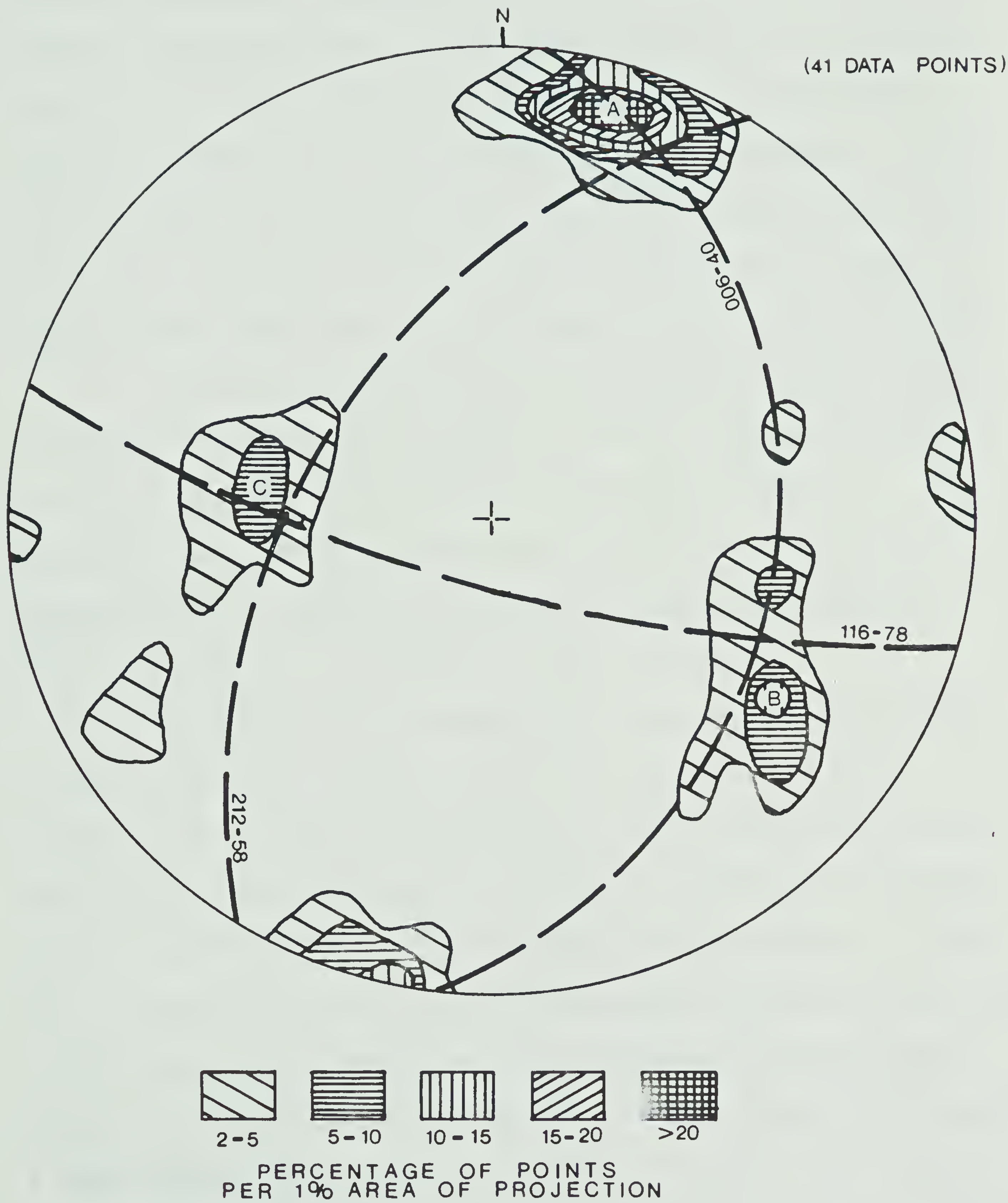

N
(41 DATA POINTS)
A
B
C
006-40
116-78
212-58
2-5
5-10
10-15
15-20
>20
PERCENTAGE OF POINTS
PER 1% AREA OF PROJECTION

FIG. 3-1

## 3.2 FORM OF THE DEPOSIT

At the turn of the century, after much of the gold had been won from the gravels of Granite Creek, interest was subsequently directed at bench deposits. It was quickly noted that a pay streak, representing a former level of the creek was present within these benches (Galloway, 1931) and that this paleochannel appeared to follow a draw through the surrounding hills (Plate IV ), approximately 1.4 km above the present mouth of Granite Creek. Hydraulicing, in 1902, exposed approximately 50 m of this channel, confirming its existence.

Based on inferences generated by long-hole drilling, raising and subdrifting within the paleochannel gravels, seismic refraction survey and airphoto interpretation it has been possible to determine further the approximate location and form of this buried channel deposit. A summary of the aforementioned test methods and their interpretation is presented in Figs. 3-2 and 3-3.

Subdrifting along the base of the paleochannel has exposed a number of features characteristic of this channel. Its base occupies a narrow (up to approximately 6 m wide), steep-walled canyon which transects argillites and volcanoclastic sediments of the Nicola Group. This bedrock has a smooth, fluvial polished surface (see Plate IV). At present the faces of two old waterfalls are known to exist within the channel. One, exposed by earlier drifting within the gravels was apparently the product of differential erosion between argillite and a quartz diabase dyke, The second face was discovered in the spring of 1978. Very little is known about this second one, except that it appears to be the remains of an old cascade with abundant giant blocks of autochthonous argillite. The channel, as exposed in the underground

Plate III

Stratified Fluvial-glacial Material That Mantles the Area Around the Mine Site.

Plate IV

Surface Expression of the Paleochannel in the Form of a Draw Through the Surrounding Hills. The Tulameen River Valley is at the Upper Left. View is Looking to the North East.

PLATE III

PLATE IV

Figure 3-2

Summary of Underground Development and

Seismic Survey Results with Inferred

Position of the Channel Also Shown

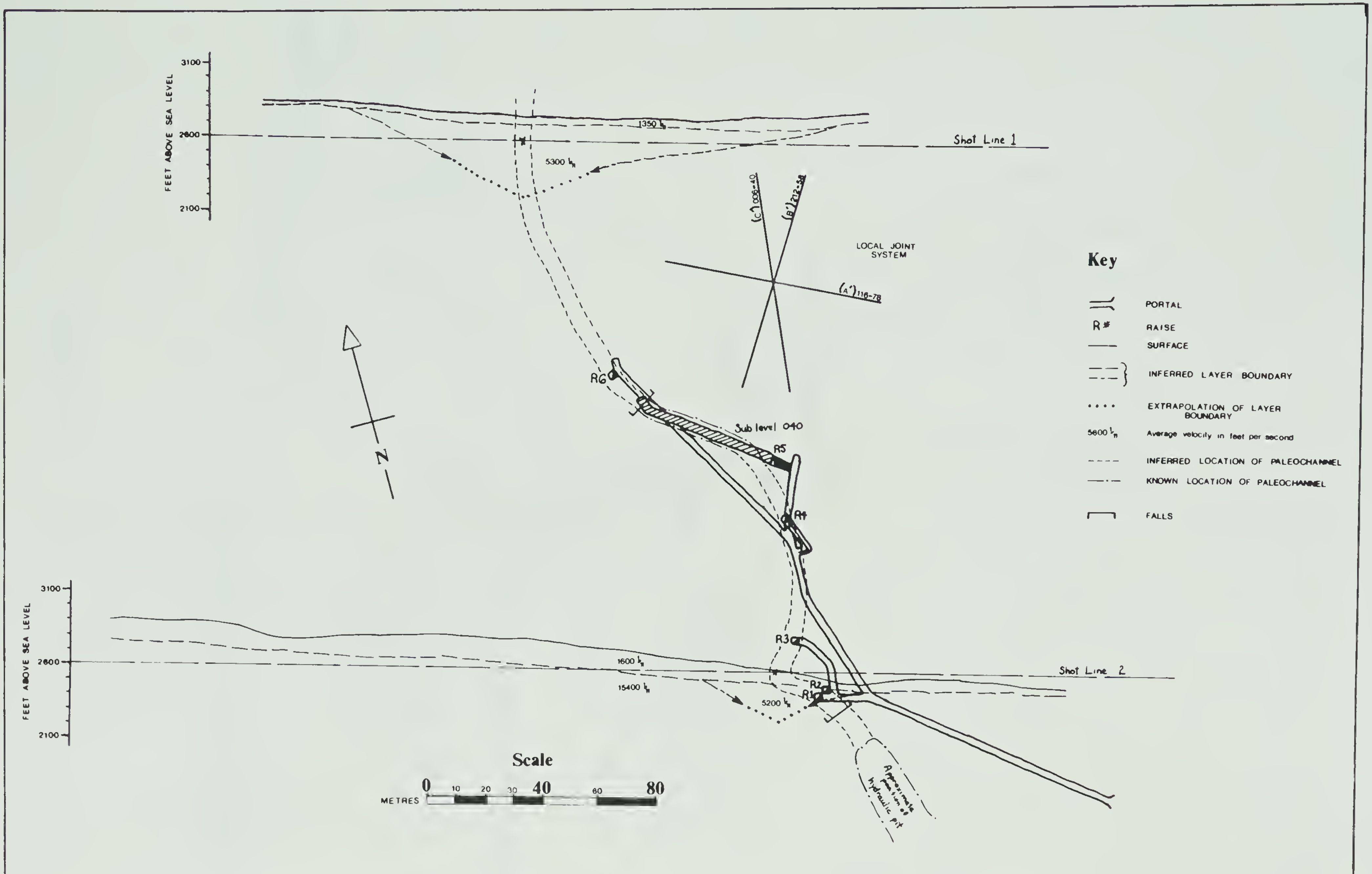
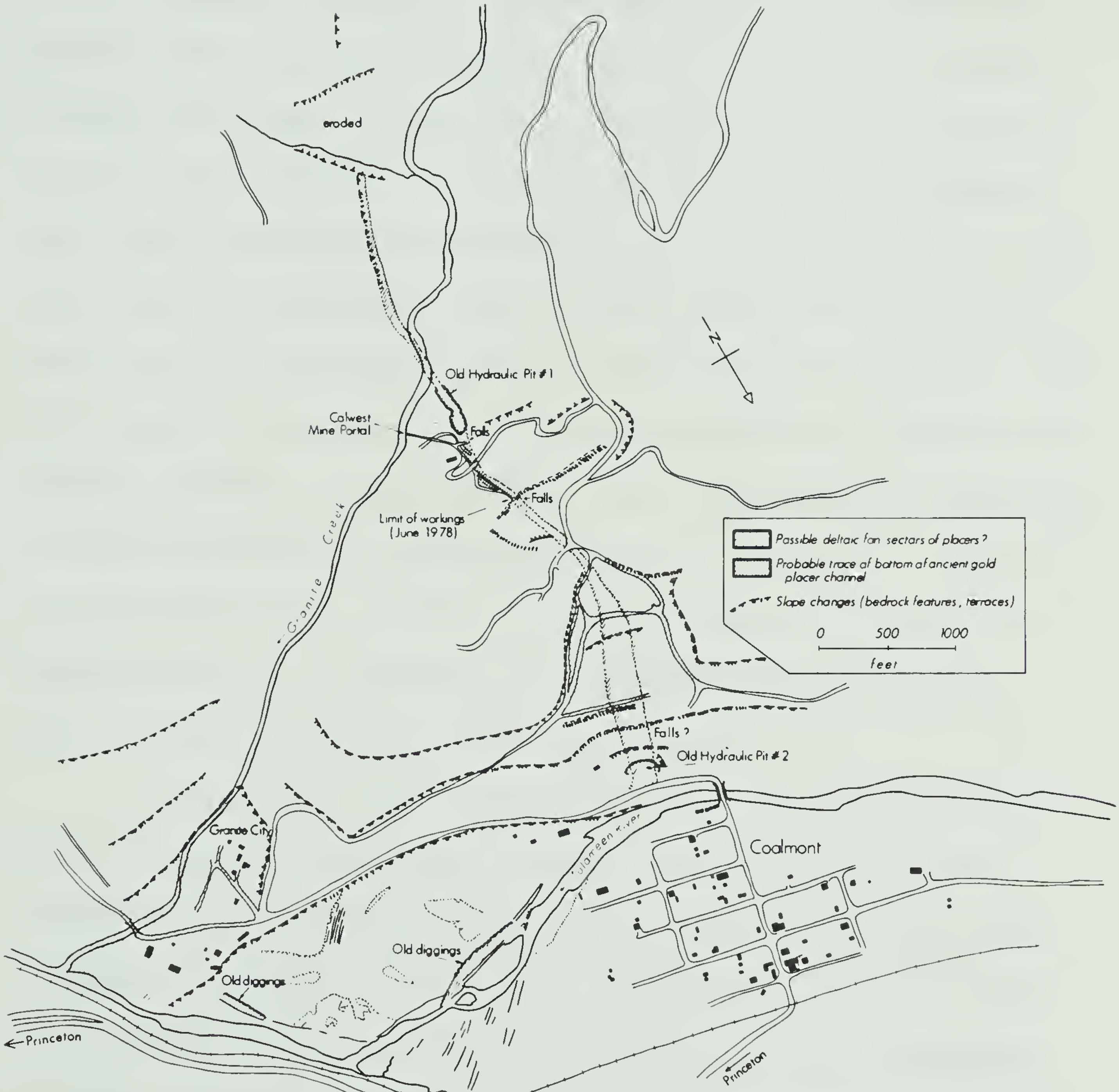

3100
2800
2100
FEET ABOVE SEA LEVEL
1350 f/s
5300 f/s
Shot Line 1
(C')006-40
(B')212-58
(A')116-78
LOCAL JOINT SYSTEM
N
R6
Sub level 040
R5
R4
R3
R2
R1
1600 f/s
15400 f/s
5200 f/s
Shot Line 2
Approximate position of hydraulic pit
Scale
0 10 20 30 40 60 80
METRES
Key
PORTAL
R#
RAISE
SURFACE
INFERRED LAYER BOUNDARY
EXTRAPOLATION OF LAYER BOUNDARY
5600 f/s
Average velocity in feet per second
INFERRED LOCATION OF PALEOCHANNEL
KNOWN LOCATION OF PALEOCHANNEL
FALLS

FIG. 3-2




Air Photo Interpretation of Granite Creek Area showing location of buried placer channel

**Fig. 3-3**

workings, and based on seismic results, has an approximate mean gradient of 5%.

The gravel within the channel consists of well-rounded to sub-angular allochthonous fragments. Present are cobbles of fine-grained volcanics, argillite, diabase and ultramafics. The latter, probably from the Tulameen Complex, include the occasional fragment of massive magnetite, hornblendite, olivine pyroxenite and dunite. The coarse sand and granule fraction consists of abundant subangular quartz and feldspar with fragments of diorite, vari-coloured volcanics, some sediments and minor volcanic breccia, gneiss and shist. All of this material is cemented by smectite clays giving it competency. Commonly associated, especially in the coarse fraction are angular, autochthonous fragments of argillite and tuff. This material is moderately to poorly sorted (with a sorting coefficient of about 3.5). There is a predominance of fine admixture relative to coarse with a median of approximately 2 mm. According to the classification of Pettijohn (1949) it is an arenaceous rudite (sandy gravel).

Schumm (1960; 1968) has noted that river channels and their fluvial sedimentary deposits are dependant upon the nature of the sediment load moved through the channel. Furthermore, these fluvial channels can be classified according to the form of the channel, and on the clay-silt ($<0.074$ mm) content of the channel-fill sediments. The latter serves as a parameter that is representative of the resistance to erosion, or general behavior of the sediments, in stream channels containing only small amounts of gravel. The effect of higher gravel content on the applicability of clay-silt content is not known. The Swan prospect paleochannel has a clay-silt content of

approximately 5%, a sinuosity of 1.3 and a width to depth ratio of approximately 40 (Schumm, 1972). Based on Table II this paleochannel deposit can be classified as being transitional between a 'mixed load' and a 'bed-load' channel (Schumm, 1968).

On the basis of a survey by the author and recommendation by R. D. Morton, a seismic refraction survey was conducted by Geotronics Surveys Ltd., of Vancouver. The purpose of this survey was to locate the buried channel. Twelve geophones were sited at 50- or 100-foot intervals along the lines of investigation. The 'two-way, in-line' seismic refraction method was used. Data were recorded from five or six shots; two between 200 and 500 feet off the ends of the line, one at each end and one or two within the spread. Recording was done using a 12-channel SIE Dresser refraction seismic system (Mark, 1977, internal company report).

A summary of the results is shown by the two profiles on Fig. 3-2. Each profile is a two-layer case except for the region of the paleochannel where it is a three-layer case. The upper layer has a velocity between 1350 and 1600 feet per second and is probably loose, unconsolidated sand and/or gravel. The channel layer has a velocity between 5000 and 5300 feet per second and is clay rich sands and gravels as exposed within the underground workings. The third layer has velocities between 15,400 and 19,400 feet per second. Such high velocities are indicative of hard competent bedrock, in this case argillite. In both profiles illustrated no bedrock velocities were obtained from the area underlying the channel due to its canyon-like nature (Mark, 1977, internal company report). This portion of the layer has been extrapolated in order to determine the approximate

Table II

Classification of Alluvial Channels. (Adapted from Schumm, 1968)

| Mode of Sediment Transport and type of Channel | % Silt and Clay Deposited in Channel Perimeter | Bedload (percentage of Total Load) | Type of River: Single Channel |
|---|---|---|---|
| Suspended Load | >20 | <3 | Stable suspended-load channel. Width-depth ratio <10; sinuosity usually >2.0; gradient relativity gentle. |
| Mixed Load | 5 - 20 | 3 - 11 | Stable mixed-load channel. Width-depth ratio >10, <40; sinuosity usually <2.0, >1.3; gradient moderate. |
| Bed-Load | <5 | >11 | Stable bed-load channel. Width-depth ratio >40; sinuosity usually <1.3; gradient relatively steep. |

location of the channel.

The channels course is in part controlled by the well-developed joint system of the bedrock. In Fig. 3-2 the trends of the three dominant joint sets are illustrated. By comparing the assumed channel location with the joint planes it becomes obvious that all three play an important part in determining the direction of the channel with the two less-dominant sets exerting the greatest control. This is probably a product of the proximity of these two subordinate joint sets, producing a zone of weakness with a mean northerly trend.

Air photo interpretation was done on scales of 1 : 55,000 and 1 : 5,510. Plate V is a stereogram illustration of the physiography of the area. Note the pass (a) through which the paleochannel runs. Other features evident are the present course of the Tulameen River (e), Granite Creek (f) and the ice-marginal channel formed by the Tulameen River during the Pleistocene (c).

Fig. 3-3 is a summary of the results from photointerpretation of stereo pairs, at a scale of 1 : 5,510. Note the many slope changes. Several of these obviously mark former terraces of the Tulameen River. Within the pass identified in Plate V are several isolated slope changes apparently not related to former levels of the Tulameen River but possibly to surface expressions of underlying bedrock features. Two of these features coincide with the two paleo-waterfalls that have been exposed in the underground workings. Therefore it is possible that several of the others to the north, may also represent similar bedrock features. Also evident is a fan-shaped widening of this pass as the Tulameen River Valley is approached. It

Plate V

Air Photo Stereopair of the

Lower Portion of Granite Creek

Key

a - pass through which paleochannel runs

b - approximate location of mine portal

c - ice-marginal channel once occupied by Tulameen River

d - The village of Coalmont

e - Tulameen River

f - Granite Creek

Scale: 1 : 55,000

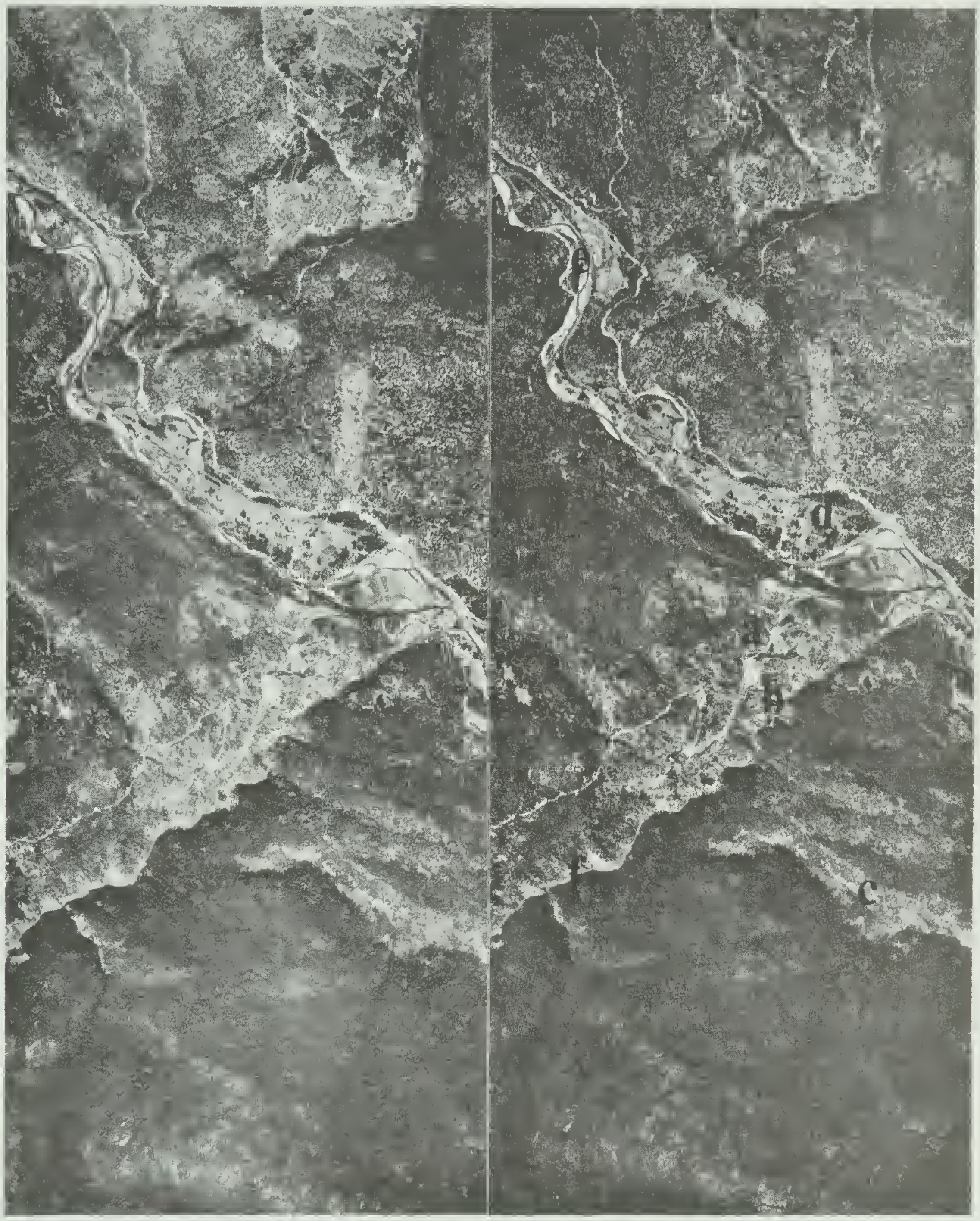



Plate V

is quite possible that this may indicate the presence of an alluvial fan, the limits of which are shown in Fig. 3-3.

Alluvial fans are cone-shaped piles of sediment deposited where streams issue from a highland onto an adjacent lowland. They are characterized by a high energy transport system, with deposition usually near the sediment source and by a wide range in clastic particle sizes (poorly sorted). When flow becomes unconfined the stream spreads laterally resulting in a decrease in water depth and velocity. At the apex of the fan the channel braids then coaleses again into a single channel at the distal portion (McGowan, 1978).

The Granite Creek paleochannel shows evidence of a number of these characteristics. Specifically these are the presence of moderately to poorly sorted gravels, probably deposited in a fairly high flow regime, and the occurence of this fan-shaped feature previously pointed out, at the edge of the Tulameen River Valley and the surrounding highlands. If such an alluvial fan is present it could be expected to constitute a major resource of auriferous and plantiniferous material of higher than average tenor.

The area around and including the paleochannel is covered by a nearly ubiquitous mantle of stratified fluvial-glacial sand and gravel (see Plate III). This sedimentary cover, of unknown thickness, probably makes up the bulk of the material within the paleostream valley. Presumably this material was deposited in the late Pleistocene, during which time ice-marginal streams and lakes were quite active in the area. Panning of some obviously fluviatile gravels intercalated with the sands and unsorted gravels has yielded minor gold values.

Plate VI

View Showing the Fluvial Polished Bedrock Surface of the Channel and the Poorly Sorted Gravels with a Weak Stratification, as Exposed in the Underground Workings.

Plate VII

Gold Nuggets Prepared for use as Jewelry (Scale is in centimetres)

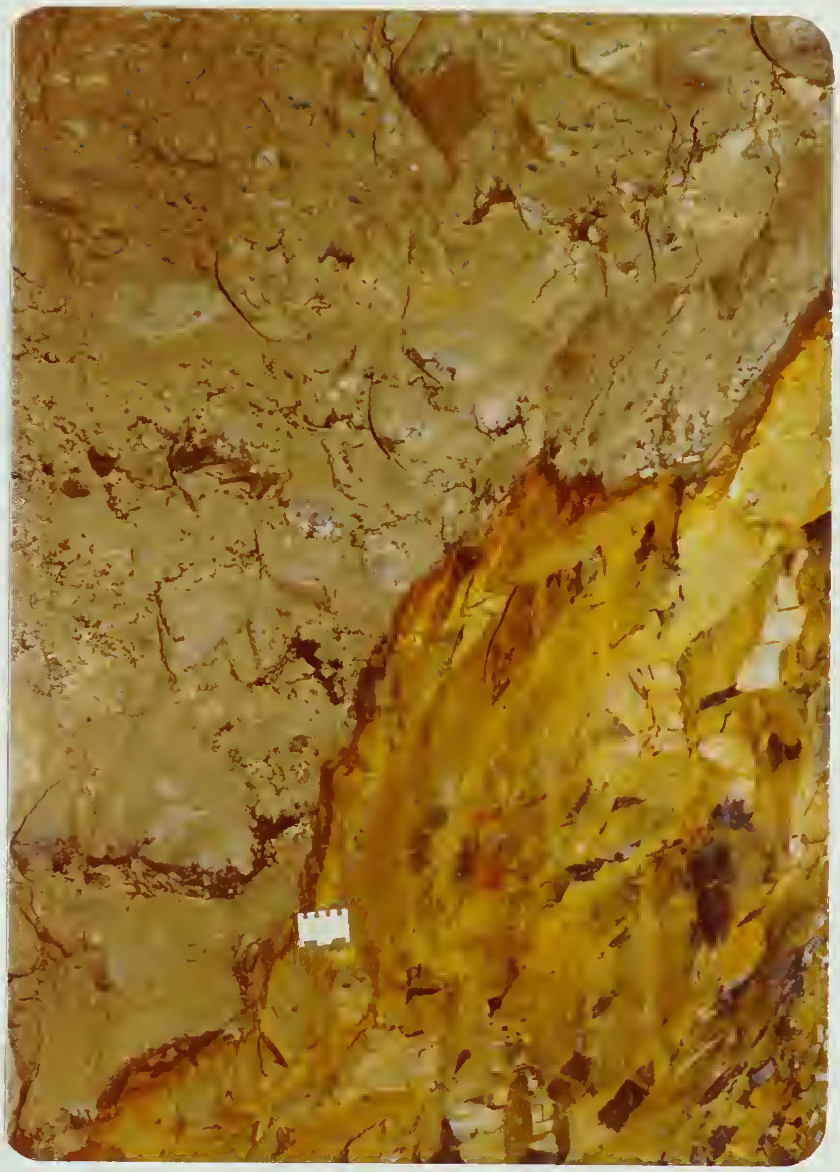


PLATE VI


PLATE VII

## 3.3 ECONOMIC GEOLOGY

Granite Creek has been a source of alluvial gold and PGE since 1885. Up to 1945 at least 25,000 oz. of gold was extracted (Holland, 1950). No production figures are available for the post-World War II period. The actual amount of gold removed from the creek is unknown, since no records have been kept regarding gold shipped south or taken away privately. Thus it can be assumed that more gold than that cited was removed from this particular stream. Table III presents the known production from Granite Creek between 1876 and 1945 that passed through Victoria, along with its values.

The gold removed from the Granite Creek placers had a fineness of 889.5 $^{o}/oo$ (Holland, 1950) which, up to 1931, corresponded to a dollar value of $18.25 per ounce crude gold. To make comparative studies, ten small nuggets from the Swan deposit, after mounting and polishing, were quantitatively analysed using wavelength dispersive electron microprobe analysis. It was found that these grains have a mean fineness of 903.0 $^{o}/oo$. It therefore appears that the gold recovered from the buried channel has a somewhat higher fineness than that from the modern alluvial placers of Granite Creek.

So far no attempt has been made to systematically test the tenor of the deposit. Timmins (1976, internal company report), after 4.7 cubic yards of material had been passed through the sluice box, recovered the concentrate generated from clean-up of the box. This sample was sent to Chemex Laboratories Ltd., in Vancouver, where it was dried, screened and analysed for gold and platinum. This sample assayed 0.1574 oz. Au and 0.03 oz. Pt per cubic yard. No attempt was made to determine the concentration of the other platinoid elements.

Table III

Gold Production From Granite Creek*

| | Ounces | Value | Present Value at CAN $263/oz. |
|---|---|---|---|
| 1876-1880 | - | - | |
| 1881-1885 | 2,959 | $ 54,000 | $ 778,220 |
| 1886-1890 | 18,905 | $345,000 | $4,972,010 |
| 1891-1895 | 2,285 | $ 41,700 | $ 600,960 |
| 1896-1900 | 55 | $ 1,000 | $ 14,470 |
| 1901-1905 | 138 | $ 2,510 | $ 36,290 |
| 1906-1910 | 9 | $ 160 | $ 2,367 |
| 1911-1915 | 108 | $ 1,970 | $ 28,400 |
| 1916-1920 | - | - | - |
| 1921-1925 | 2 | $ 39 | $ 526 |
| 1926-1930 | 117 | $ 3,787 | $ 30,770 |
| 1931-1935 | 196 | $ 4,512 | $ 51,550 |
| 1936-1940 | 252 | $ 7,763 | $ 66,280 |
| 1941-1945 | 53 | $ 1,797 | $ 13,940 |
| Total | 25,079 | $464,238 | $6,595,783 |

* From Holland (1950)

Cochrane (1977, internal company report), a year later, collected the concentrate produced from sluicing 50 cubic yards of material from the paleochannel. This material was sent to Delta Smelting and Refining Company Limited of Richmond, British Columbia, where the gold was separated from the platinum and blacksands. This concentrate yielded 13.665 oz. of gold (i.e. 0.273 oz. Au per yard). No attempt was made to determine the concentration of platinoid elements.

The only bulk 'platinum' analyses to date are those of Timmins, already cited, and by G.C. Hoffman (Camsell, 1913). The latter is a relatively complete analysis, including the major platinoid elements, that approximates the composition of Pt-Fe alloy. It has been found by the author and by Raicevic and Cabri (1976) that Pt-Fe alloy is by far the most common platinoid mineral present in these deposits. This Pt-Fe alloy is a complex alloy consisting primarily of Pt and Fe with Ir, Os and Cu. The mean composition of the Pt-Fe alloy as determined by microprobe analysis of several platinoid grains is as follows:

| | | Estimated tenor (oz./cu. yd.) | Price US $/oz. |
|---|---|---|---|
| Pt | 68.65 | 0.03 | $260 (N.M., Oct. 5, 1978) |
| Ir | 13.34 | 0.0058 | $310 (EMJ, Aug., 1978) |
| Os | 0.16 | 0.0001 | $155 (EMJ, Aug., 1978) |
| Rh | 0.19 | 0.0004 | $500 (EMJ, Aug., 1978) |
| Ru | 0.03 | 0.0 | $ 65 (EMJ, Aug., 1978) |
| Fe | 14.53 | | |
| Cu | 0.65 | | |
| Ni | 1.08 | | |
| Total | 99.41% | | |

Based on these data a minimum value can be calculated for the yet unmined portion of the paleochannel. This is based on several key assumptions. First is that development will be done by 8' by 15' drifts, and second is that the average tenor is 0.15 oz./yd.

Potential Reserves:

(a) North Section

$$\frac{8' \times 15' \times 2360'}{27} = 10{,}500 \text{ cubic yards}$$

(b) South Section

$$\frac{8' \times 15' \times 1230'}{27} = 5{,}450 \text{ cubic yards}$$

Gross Worth:

Gold - US $221.40/oz. (Northern Miner, Oct. 5, 1978)

- tenor is assumed to be 0.150 oz. per yard

| | | | |
|---|---|---|---|
| Au | (0.15 x 903$^{o}$/oo x 221.40) | = | 29.9886 |
| Pt | (0.3 x US $260) | = | 7.8000 |
| Ir | (0.0058 x US $310) | = | 1.7980 |
| Os | (0.0001 x US $155) | = | 0.0155 |
| Rh | (0.0004 x US $500) | = | 0.2000 |
| Ru | (0.0 x US $65) | = | 0.0 |

Total US $39.8021/cubic yard

CAN $47.3565/cubic yard*

* Assuming an exchange rate of 118.98¢ Canadian per US $ (Oct. 3, 1978)

a) North Section

10,500 x 47.36 = $497,243

b) South Section

5,450 x 47.36 = $258,093

Total = $755,336

As mentioned previously this value represents only a minimum value. In actual fact the potential worth is significantly higher due to several factors. Foremost is that the precious metals may not be sold for metallurgical but, rather, for their aesthetic or scientific value. The gold (see Plate VII) is presently being sold for jewelry and commands a premium of at least a third over the current price of refined gold. At present no similar market has been developed for the PGE but the potential is there, especially in the form of museum and research specimens.

Another factor is the assumption that a working face of 8' x 15' will be used. It has been noted by Cochrane and by Morton (1977; 1978, internal company reports) that there does not appear to be any obvious concentration of the precious metals in the lower portions of the channel bed. In fact, it is not uncommon to have the gold scattered throughout a deposit without any significant bedrock enrichment (Wells, 1973). Thus, these unsorted auriferous gravels may occupy a thickness much greater than that removed in 8 foot high stopes.

The third factor is that of the tenors chosen for the preceding calculations. Based on the findings of Timmins and of Cochrane (1976; 1977, internal company reports) the tenor of the gravels

would appear to be greater than 0.15 oz/cubic yard. As previously alluded to an alluvial fan structure may be present in the northern section of the channel which, if it actually exists, can be expected to yield higher than normal tenors. Therefore, the average tenor of the deposit probably approaches, or even surpasses 0.200 oz. per yard. Only detailed production records as mining progresses can substantiate this conclusion.

Thus the absolute mining return to be expected from known potential reserves is at least $755,000. After one takes into consideration the true prices received as well as a higher and more realistic tenor, the gross worth then approaches $1 million in value. Furthermore, if reserves can be increased by the use of more efficient or larger-scale mining methods, the gross value of this deposit can be expected to increase proportionally. It is therefore apparent that though this is a small mine it has great potential as a large producer.

Of special importance for the most efficient exploitation of potential reserves is the development of a method for removing the maximum amount of material at the lowest possible cost. One option is open-pit mining. This method is typically capital intensive and would require an accurate appraisal of the full value of the deposit. Since no detailed sampling has been done on the Swan Prospect it is impossible to determine whether this method might prove to be economical.

Other possibilities are more labour intensive and therefore require a much smaller initial capital outlay. Up until recently development has been done by drifting in the channel gravels. This method has a disadvantage in that full-timbering of the drift is required, thus adding extra costs and restricting the amount of material

that can be removed. Presently development is being done by drifting below the channel and by construction of finger raises. This sublevel stoping is perfectly suited to this form of deposit. The walls of the channel are steeply dipping and are stable. The gravels are cemented by a fairly high smectite clay content and so are relatively competent. The advantage of this method is that as much material as desired can be removed. Also, it uses gravity to the best advantage.

As of November 30, 1977, $333,569 has been expended on the development of the property. Cal-West Petroleums Limited by their acquisition of Harkor Developments Limited inherited $169,109 in deferred development costs. Since that time, $122,770 has been spent on exploration and development. Of this 64% was for labour costs and the rental and maintainance of equipment. The balance, $41,690, were administrative costs.

The Swan prospect has potential for producing a net return on investment. Up to the present, development has included construction of an all-weather sluicing plant, drifting below, raising into and subdrifting in the channel. Material is removed by a narrow gauge, pneumatic locomotive and several side-dump cars. Production has been sporadic due to equipment down-time and to financial difficulties.

It is felt that the mine is now on the threshold of coming into full production. Before this happens, a detailed survey involving high-resolution seismic and/or churn drilling of the channel is clearly necessary. Such surveys would provide better definition of the channel location from which to plan further underground development. Furthermore, a drilling program, if initiated, would resolve the dis-

tribution of gold and PGE in the section above the channel base.

Care must be exercised with a drill program in order to get satisfactory results. It is recommended that a hole diameter of no less than 7½" be used in order to reduce the effect of the addition or loss of even a small amount of gold in an assay. Also, care should be taken to maintain a plug at the drive shoe to prevent contamination (Wells, 1973). Though other types of placer drills are available, the churn drill is recommended since it is a proven method and its inherent simplicity should help reduce overall costs. This would provide the data required to ascertain which mining method is the most economically feasible. Also required is a more efficient locomotive, such as a diesel or electric powered unit. This would ensure a more rapid transfer of more material than the present unit in operation.

# CHAPTER FOUR

## MINERALOGY OF OPAQUE PHASES IN THE CONCENTRATES

### 4.1. MINERALOGY OF THE BLACK SANDS

The principal constituent of the heavy mineral separates produced by sluicing the auriferous gravels is 'black sand'. This 'black sand' fraction consists predominantly of sand- to cobble-sized, well-rounded fragments of magnetite. A representative sample consisting of ten small pebbles was mounted and polished in order to determine the mineralogy.

These pebbles consist of interlocking brownish grey anhedral to subhedral, fine-grained magnetite. Commonly xenomorphic inclusions of dark grey spinel are present along the grain boundaries and as lamellar intergrowths, following the octahedral planes of the magnetite. Martitization, in various degrees of development, is common. Usually the hematite occurs as regular to tapered laths, primarily near grain boundaries, and as irregular replacements along octahedral planes. The degree of martitization is usually slight but does vary up to approximately 10%.

Commonly associated with the magnetite are scattered xenomorphic grains of ilmenite. The ilmenite is pinkish grey in color with strong bireflectance and anisotropy. Occasionally the ilmenite grains have inclusions of hematite. The hematite is present as extremely small, orientated, rod-like blebs or as fine-scale myrmekitic intergrowths.

## 4.2 SIZE ANALYSIS OF THE PRECIOUS METALS

Size analysis was carried out on a sample of gold-platinum concentrate from the Granite Creek deposit. The concentrate was first coned and quartered. From the resultant sample a random selection of nuggets was made. These were then measured, using a micrometer, to determine length, breadth and thickness. Using these data, Corey shape factors were then calculated and frequency diagrams plotted (see Figs. 4-1a and 4-2a).

The Corey shape factor is widely used in engineering problems dealing with sedimentation. It is defined as being the square root of the ratio of thickness squared to length x breadth and is given by the equation:

$$\text{Corey shape factor} = \sqrt{\frac{T^2}{L \times B}}$$

Small Corey factors are indicative of flattened grains, whereas large factors indicate the grains are more spherical (Tourtelot and Riley, 1973). Malleable native metals, in particular gold, show a distinct tendency to become smaller and more flattened out the further they have been transported. Thus the Corey factor, in association with size, might give an indication of the degree of transport placer gold has undergone.

Figs. 4-1a through c present frequency diagrams for several different gold placer deposits. It will be noted that all are positively skewed. Whereas the Granite Creek gold exhibits a distinct leptokurtosis, the other two are more mesokurtic, with a tendency towards a normal distribution as the mode attains larger Corey factors.

Figure 4-1

Size Analysis of Gold from Several

North American Placer Deposits.

(Note the Decrease in Kurtosis and

Skewness as One Goes From a to c

Implying a Decrease in Maturity.)

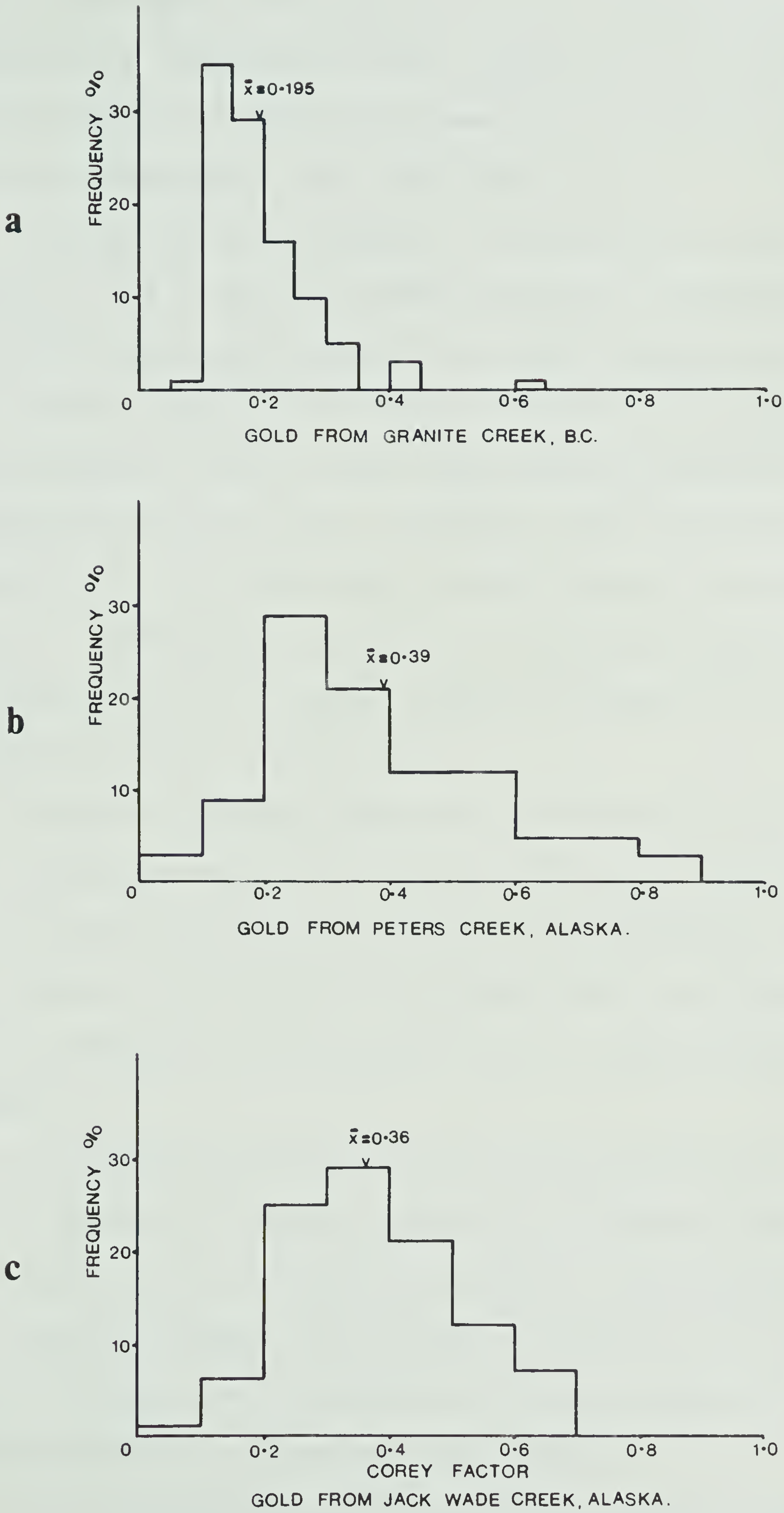

a
FREQUENCY %
30
20
10
x̄=0·195
0
0·2
0·4
0·6
0·8
1·0
GOLD FROM GRANITE CREEK, B.C.
b
FREQUENCY %
30
20
10
x̄=0·39
0
0·2
0·4
0·6
0·8
1·0
GOLD FROM PETERS CREEK, ALASKA.
c
FREQUENCY %
30
20
10
x̄=0·36
0
0·2
0·4
0·6
0·8
1·0
COREY FACTOR
GOLD FROM JACK WADE CREEK, ALASKA.

FIG. 4-1

From this it would appear that immature gold placer deposits are characterized by an approximately normal distribution but, with transport, the plot takes on a distinctly asymmetrical distribution with gold appearing to approach a Corey factor limit of 0.1.

Platinum from placer deposits, as illustrated by Figs. 4-2a through c, tend to vary more between platykurtic and mesokurtic, with a tendency towards the development of bimodal distributions. As with gold, kurtosis appears to be related to maturity of the deposit, with the more immature deposits being characterized by platykurtosis. With transport the platinum tends to approach a mean Corey factor of approximately 0.55. This relationship, whereby kurtosis is related to maturity, is substantiated in part by the Goodnews Bay deposit where the platinum occurs in gravels composed by subangular to rounded pebbles and small cobbles (Mertie, 1969).

The gold and platinum samples from Granite Creek averaged 4.2 and 3.6 mm respectively in size, which is more than 6 times the average of 0.5 mm or less for the Alaskan gold and platinum and the Columbian platinum. This difference is probably due to the difference in size and concentration of the precious metals in their respective source rocks.

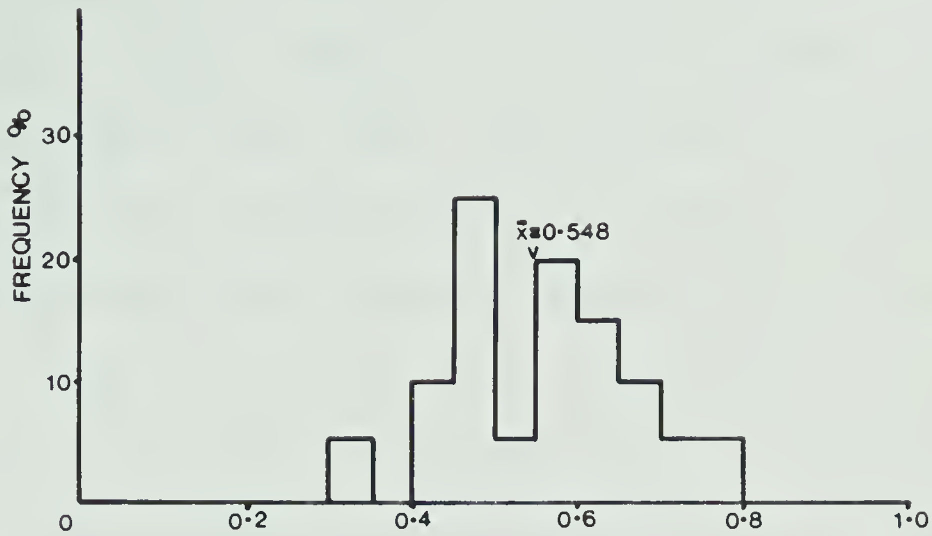
In conclusion it is obvious that the gold and platinum found in the Granite Creek deposit originated from relatively high grade lode deposits. Upon liberation by weathering they subsequently underwent extensive transport and/or reworking resulting in the gold becoming well flattened and the platinum attaining an approximate ellipsoidal equilibrium configuration of the grains.

It is worthy to note that the gold from previously exploited

Figure 4-2

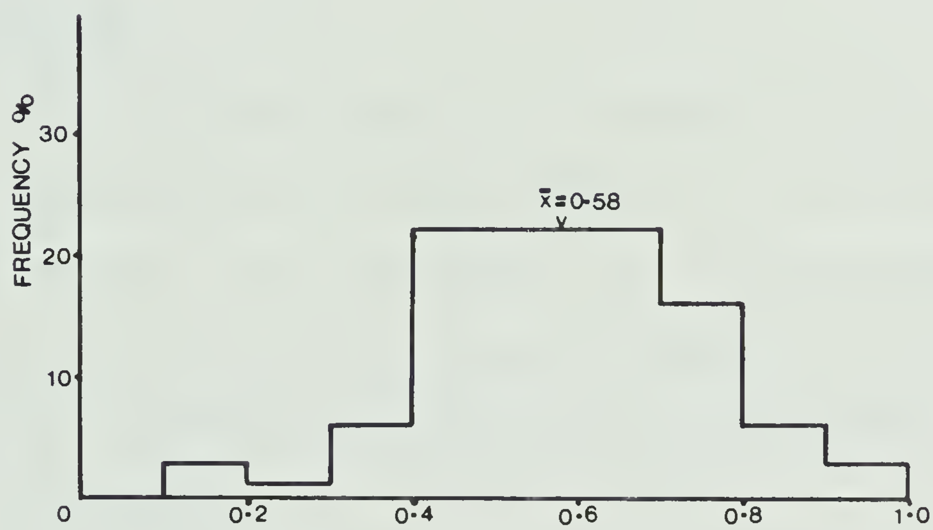
Size Analysis of Platinum (PGE nuggets) From Several Localities in North and South America. (Note the Tendency Towards Bimodality and the Decrease in Symmetry as One Goes from a to c, as in Fig. 4-1, Implying a Decrease in Maturity.)

a



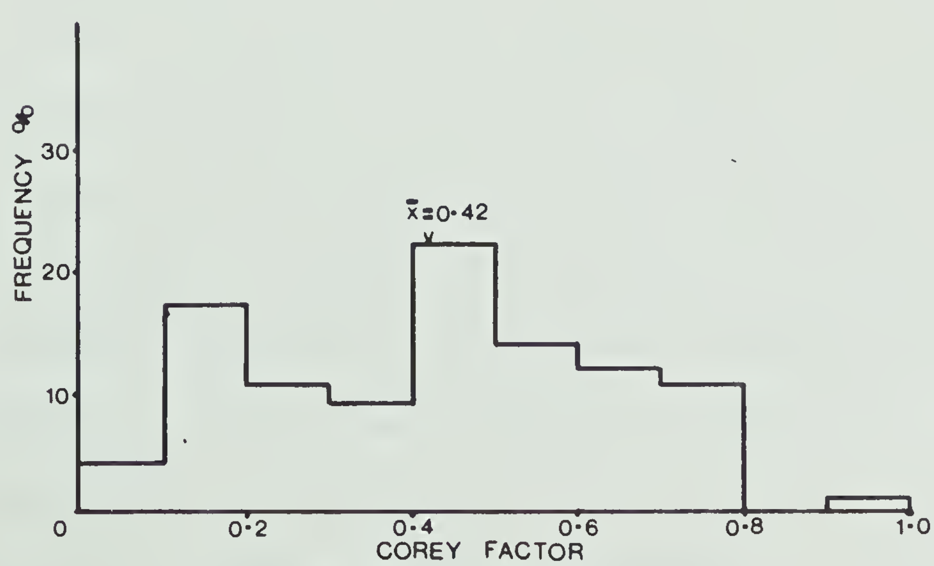

PLATINUM FROM GRANITE CREEK, B.C.

b




PLATINUM FROM GOODNEWS BAY, ALASKA.

c




PLATINUM FROM NARIÑO, COLUMBIA.

FIG. 4-2

placer deposits on Granite Creek was not well flattened. Rather, the gold occured as rough, angular or slightly flattened, but rarely well-flattened nuggets (Rice, 1947). This has been further substantiated by Raicevic and Cabri (1976), in a study on the Au-Pt placers of the Tulameen River farther downstream from the mouth of Granite Creek. This would tend to indicate that many of the recent placer deposits in the area are a direct product of erosion of auriferous lode deposits rather than reworking of older placer deposits, such as the Swan deposit.

## 4.3 GOLD MINERALOGY

The gold recovered from the Swan Prospect is usually well flattened with approximately 25% being elongated to the extent that the length is more than twice the breadth. The average breadth of the grains is 4.4 mm with the extremes being approximately 1 mm and 17 mm (see Plates VIII through X). Occasionally fragments of white quartz are found still attached.

After microhardness and reflectivity determinations were made, the gold grains were then analysed utilizing an ARL EMX electron microprobe in order to determine their compositions and to test for peripheral depletion of silver, a phenomenon common in alluvial placers.

The grains studied consist exclusively of gold and silver though, in some, copper in amounts no greater than 1% may also be present. Each grain was found to be essentially homogenous with no apparent depletion in silver content towards the edge of the grains. There is no uniformity in composition between grains with fineness varying from a low of 85.8% Au to a high of 94.7% Au. The mean com-

Plate VIII

Sample of Gold and PGE Nuggets

from the Swan Prospect.

(Scale is in centimetres)

Plate IX

Close up of Gold Nuggets.

Note How Flat They Are. (Low Corey Factor)

(Scale is in centimetres)

PLATE VIII


PLATE IX

Plate X

Several Large Gold Nuggets.
Note the Attached Quartz On the
One to the Lower Right.
(Scale is in centimetres)

Plate XI

PGE Nuggets Recovered from the
Swan Prospect. Black Splotches are
Chromite and Magnetite Inclusions.
(Scale is in centimetres)


PLATE X


PLATE XI

position of these grains is 90.30 ± 2.63% Au and 8.67 ± 2.83% Ag.

Microindentation hardness (VHN) was determined using a Vickers Micro Indenter objective and associated compressed air transmitter. A load of 100 g was applied for 30 seconds. In all cases the impressions were found to be near perfect though some minor distortion of the surrounding grain was common. Frequently the side of the impressions were slightly concavo-convex. The results, plotted against composition, are given in Fig. 4-3. Also shown is the regression line for these data. The correlation coefficient is 0.6666.

Reflectivity measurements were accomplished using an Indumess miniphotometer adapted to the accessory monocular on a Zeiss Universal M microscope. Light filtration was done with a Schott PIL 0.5 monochromatic filter producing green light with a wavelength of 547 nm. The reflectance standard used was NBS standard reflectance material #2007 (gold on glass) having a reflectance of 79.1% at 546 nm. Ten concurrent measurements were made on each grain and from these the mean was then determined. The results, plotted against concentration, are presented in Fig. 4-4. As with the VHN results, regression analysis was done on the data. The resultant line, shown by the dashed line, has a correlation coefficient of 0.7173.

It is clear that in both Figs. 4-3 and 4-4 there is a weak correlation between microhardness and reflectance with composition. With respect to the latter case, it has been shown by Eales (1967) that there exists a strong relationship between reflectance and fineness of gold-silver alloys, but that the reflectance measured is strongly dependent upon the quality of polish. Different polishing

Figure 4-3

Vickers Microindentation Hardness of Gold From The Swan Prospect Plotted Against Composition. (The Regression Line (dashed line) has a Correlation Coefficient of 0.7 Indicating A Weak Linear Relationship).

Figure 4-4

Reflectivity of Gold From the Swan Prospect Plotted Against Composition. (The Regression Line (dashed line) has a Correlation Coefficient of 0.7 Implying a Weak Linear Relationship).

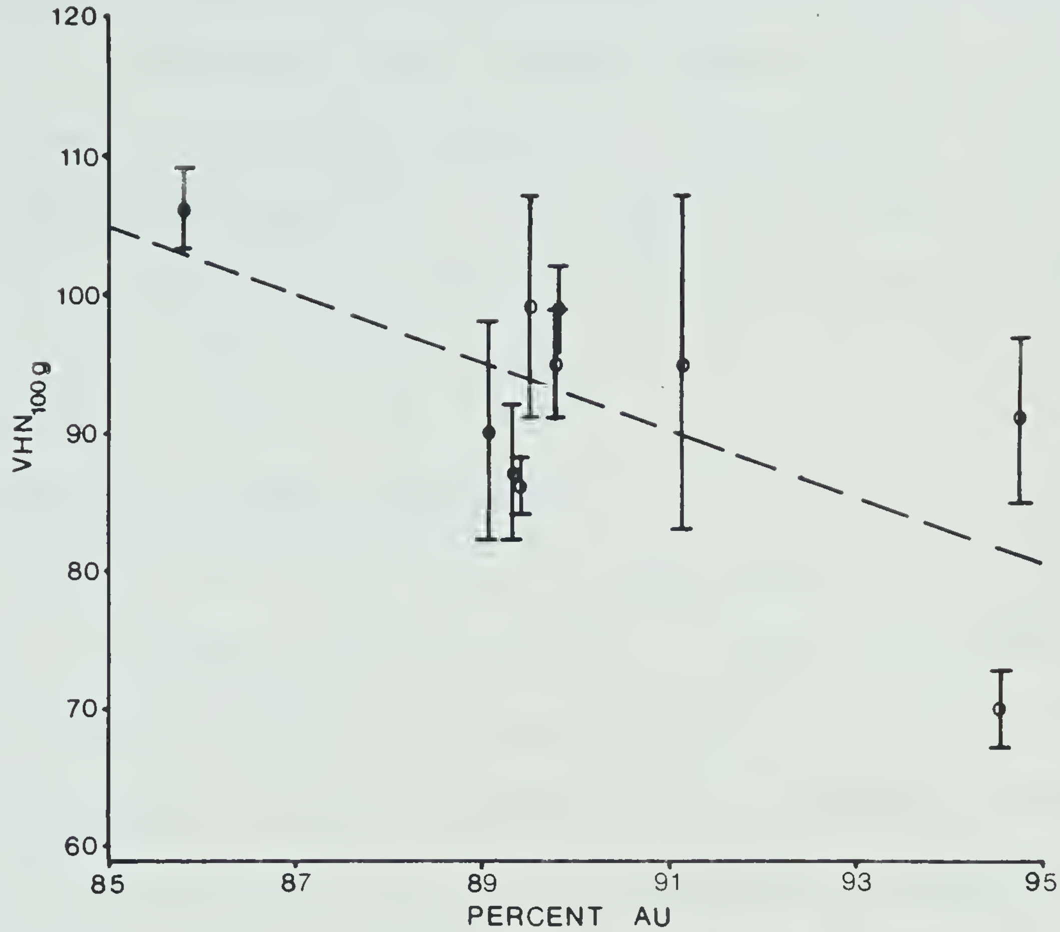

120
110
100
90
80
70
60
VHN100 g
85
87
89
91
93
95
PERCENT AU

FIG. 4-3

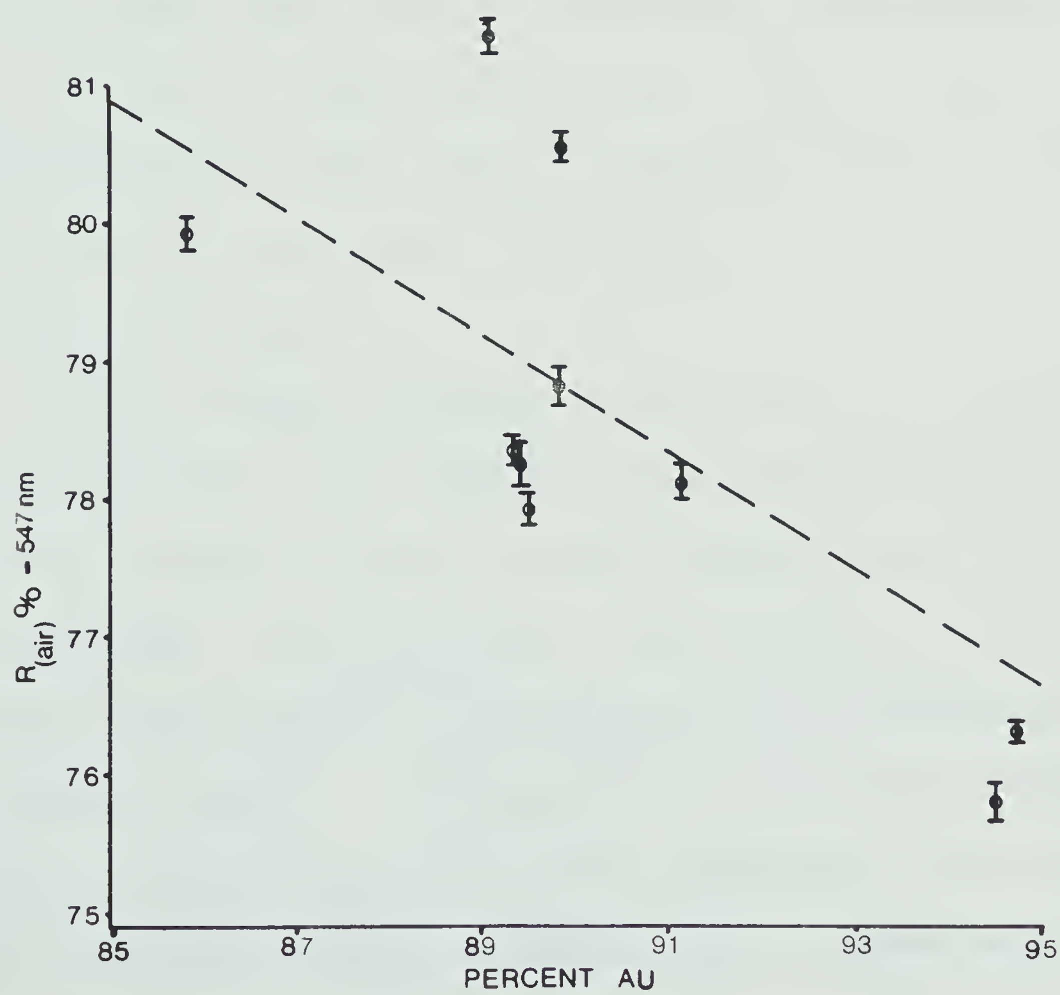

81
80
79
78
77
76
75
R(air)% - 547 nm
85
87
89
91
93
95
PERCENT AU

FIG. 4-4

techniques produce different degrees of deformation of the surface layer and so, in the case of gold, produce profound effects on the optical properties. Also the wavelength of light used has a marked effect on reflectance sensitivity. For example, the range of reflectance values for well polished gold and silver at 470 nm is more than twice that at 541 nm (Eales, 1967).

## 4.4 PLATINUM GROUP ELEMENT MINERALOGY

The bulk gold to PGE ratio is approximately 5 : 1 for the Swan deposit. The PGE grains are actually a complex association of a number of different platinoid minerals. They are generally ellipsoidal in shape with an average breadth of 3.6 mm and with extremes of about 6.6 and 1 mm (see Plate XI). Tiny chromite and magnetite grains are commonly found adhering to the surface, as are the occasional olivine and pyroxene grain. The PGE nuggets are silvery white in colour with a smooth but well pitted surface. Previous studies have shown that approximately 40% of the PGE nuggets extracted from the deposits of the area are magnetic (Kemp, 1902; Camsell, 1913; Raicevic and Cabri, 1976).

A total of seven PGE nuggets (see Figure 4-5), supplied by Cal-West Petroleum Ltd., were studied. After mounting and polishing they were first studied utilizing a Zeiss Universal M reflected light research microscope. Microindentation and reflectivity determinations, using the apparatus previously described under gold mineralogy, were made on selected minerals. Compositions of the minerals found were then determined using an Applied Research Laboratories EMX electron microprobe with Energy Dispersive Analysis (EDA) and Wavelength Dis-

Figure 4-5

Examples of PGE Nuggets Recovered From the Swan Prospect.

<u>Key</u>

a Pt-Fe alloy

b osmiridium (not shown but common as minute inclusions in grains a, b, c, d, and g)

c platiniridium

d laurite

e tulameenite

ganque - commonly chromite

(Bar scale represents 1 mm).

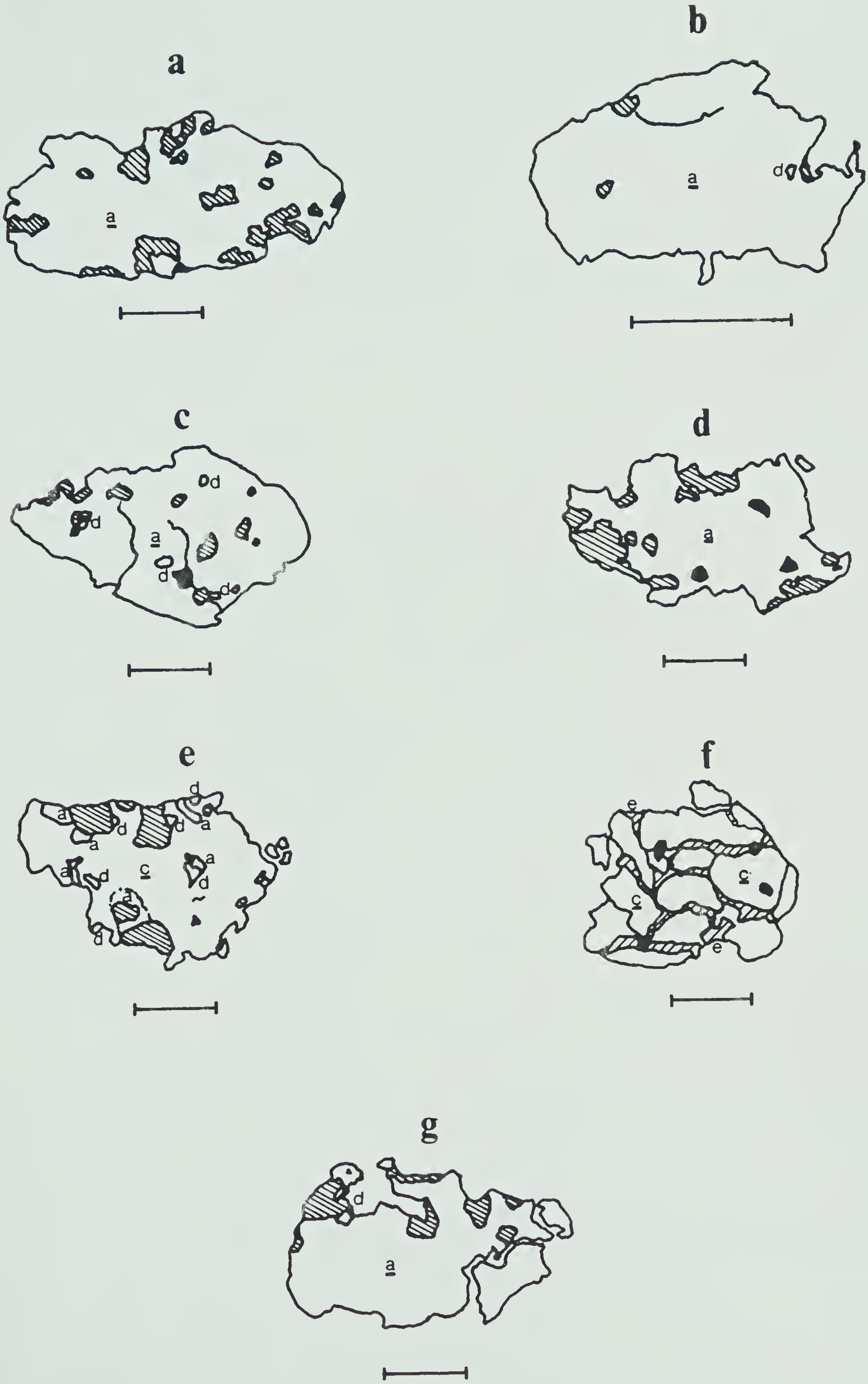



FIG. 4-5

Figure 4-6

Reconnaissance EDA Spectra for a Number Of PGE Minerals and Alloys (Log Scale).

a) Pt-Fe alloy with minor Cu and Rh

b) Osmiridium with some Pt and Ru

c) RhSb with minor Fe (unnamed mineral)

d) (Rh,Ir)SbS (unnamed mineral)

e) sulphosalt analogous to braggite [(Pt,Pd,Ni)S] but with Ir and Rh replacing Pt and Pd.

f) $PtAu_4Cu_5$ (unnamed alloy).

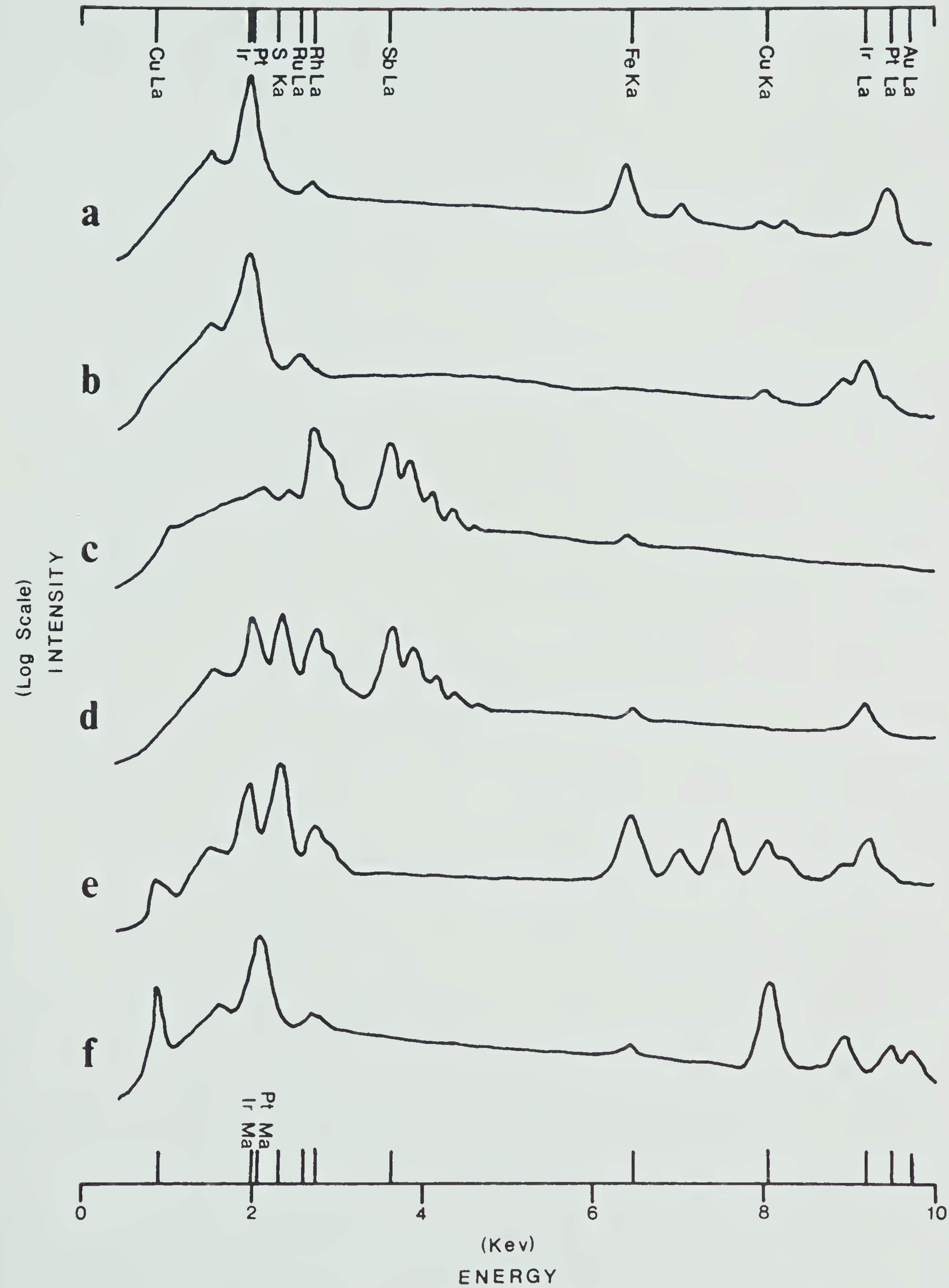

Cu La
Pt
Ir
S Ka
Ru La
Rh La
Sb La
Fe Ka
Cu Ka
Ir La
Pt La
Au La
a
b
c
d
e
f
(Log Scale)
INTENSITY
Pt Ma
Ir Ma
0
2
4
6
8
10
(Kev)
ENERGY

FIG. 4-6

Figure 4-7

Reconnaissance EDA Spectra for a Number of PGE Minerals and Alloys (linear intensity scale).

a) sulphosalt analogous to braggite [(Pt,Pd,Ni)S] but with Ir being the major PGE (similar to Fig. 4-6e).

b) laurite [$RuS_2$] with some Ir.

c) (Rh,Ir)SbS - unnamed mineral similar in composition to Irarsite [(Ir,Ru,Rh,Pt)AsS] but with Sb replacing the As.

d) Pt-Fe alloy

e) $PtAu_4Cu_5$ (unnamed alloy)


a
b
c
d
e
INTENSITY
0
Cu La
Ir Ma
Pt Ma
S Ka
Ru La
Rh La
Sb La
Fe Ka
Cu Ka
Ir La
Pt La
Au La
0
2
4
6
8
10
(KEV)
ENERGY

FIG. 4-7

persive Analysis (WDA) capabilities.

In order to determine what minerals were present in the seven grains studied, reconnaissance qualitative analysis was first done utilizing the EDA capabilities of the microprobe. CRT display results for a number of selected minerals are presented in Fig. 4-6 and Fig. 4-7.

(a) Major PGE Minerals

The grains studied consist primarily of a platinum-iron alloy. Since no data on the chemical structure is available, this general name of platinum-iron alloy, as defined by Cabri and Feather (1975), will be used. This Pt-Fe alloy is light greyish white in colour with no bireflectance or anisotropy in reflected light, in air.* Reflectance appears to vary with Fe content. R% (547 nm) is 63.4 for a Pt-Fe alloy with 16.6 wt. % Fe and 69.4 for 10.0 wt. % Fe. Vickers microindentation hardness for a 50 g load varies between 419 ± 35 and 476 ± 58 kg/sq. mm. These results are lower than the values reported by Cabri *et al.* (1973) for Pt-Fe alloy from the same district.

Common within the Pt-Fe alloy are tiny (usually less than 5 μ), rounded, inclusions of osmiridium. Also present are large (up to about 0.5 mm) inclusions of chromite, and occasional magnetite and olivine. Grain d (Fig. 4-5) is notable in that magnetite occurs as abundant, minute, vermicular intergrowths within the Pt-Fe alloy (see Plate XII-1). Other minerals present as inclusions are laurite ($RuS_2$),

---

* All optical determinations, including reflectance, were made in air unless otherwise noted.

Plate XII

1. Inclusions of magnetite intergrowths (b) in Pt-Fe alloy (c).

   Note the plates of iridosmine (a)

   Crossed Nicols and Nomarsky Phase Interference Contrast.

2. Exsolution of tulameenite (a) in platiniridium (b)

   Crossed Nicols and Nomarsky Phase Interference Contrast.

3. $PtAu_4Cu_5$ (a) and RhSb (c) in tulameenite. Note the exsolution blebs of tulameenite in platiniridium (d). Not apparent but present are exsolution blebs of platiniridium within the tulameenite. Directly above the scale bar is an unnamed pseudo-braggite mineral.

   Plane Light

4. Laurite (a) intergrowths in platiniridium (c). Note the vein of Pt-Fe alloy (b).

   Plane Light

5. Platy crystals of osmiridium (a) enclosing intersertal laurite (b). Groundmass is Pt-Fe alloy (c) and dark mineral is chromite.

   Crossed Nicols and Nomarsky Phase Interference Contrast.

6. Inclusions of laurite (a) and Pt-Fe alloy (b) in platiniridium (c).

   Plane Light

7. Subhedral inclusions of laurite (a) and rounded inclusions of osmiridium (b) in Pt-Fe alloy.

   Plane Light.

8. Inclusions of an unnamed pseudo-braggite mineral.(a), (Ir,Rh)SbS (b), osmiridium (c) and chalcocite (d) in Pt-Fe alloy.

   Plane Light

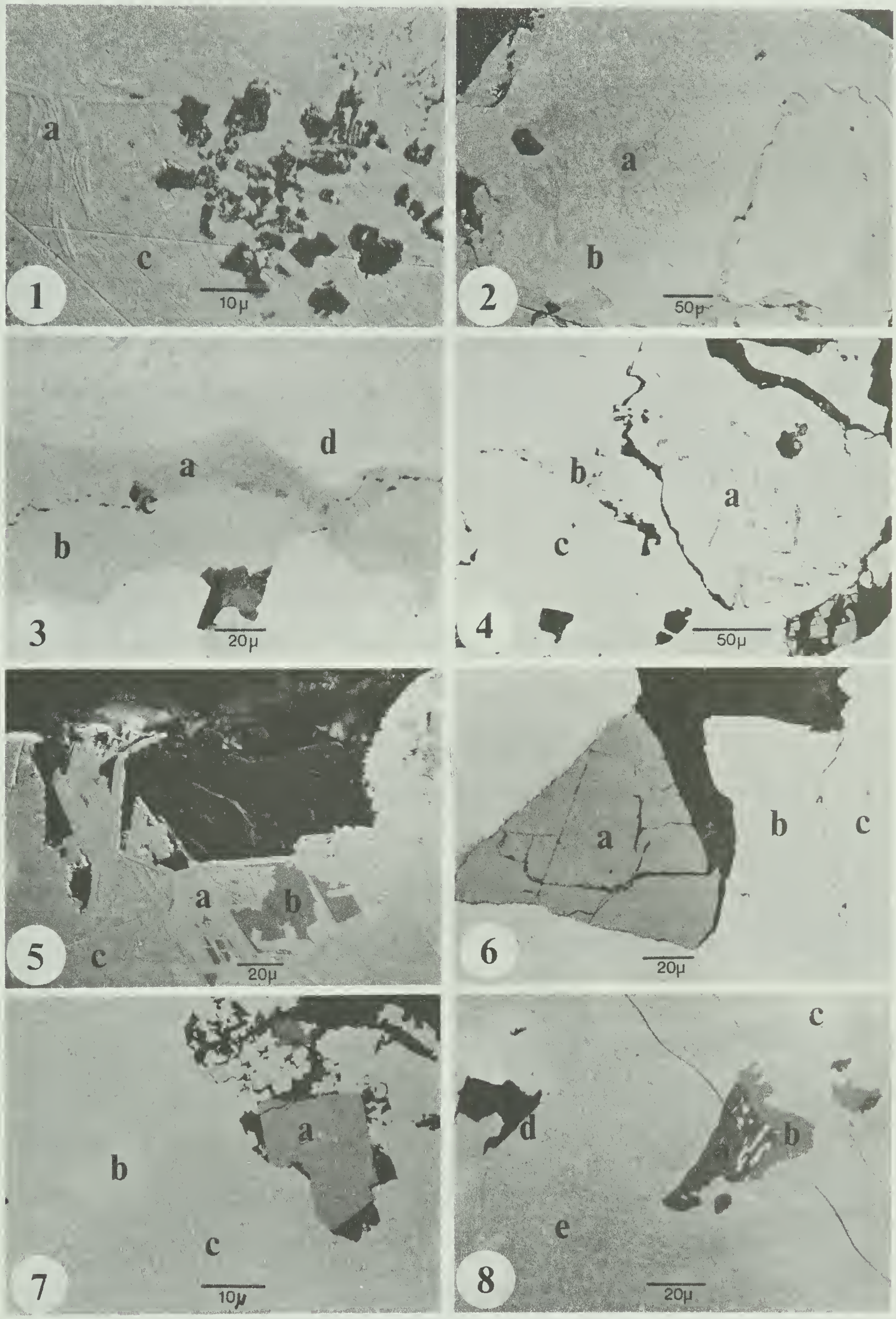

1
a
c
10μ
2
a
b
50μ
3
a
b
c
d
20μ
4
a
b
c
50μ
5
a
b
c
20μ
6
a
b
c
20μ
7
a
b
c
10μ
8
b
c
d
e
20μ

**Plate XII**

iridosmine (Os,Ir), tulameenite ($Pt_2FeCu$), (Ir,Rh)SbS, pyrrhotite ($Fe_{1-x}S$), chalcocite ($Cu_2S$) and several sulphosalts analogous to braggite ([Pt,Pd,Ni]S).

Tulameenite is present associated with a Pt-Fe alloy in grain c and with platiniridium in grain f. It occurs as an outer zone of the Pt-Fe alloy and, as noted by Cabri *et al.* (1973), is characterized by a relatively inferior polished surface. Grain f consists of platiniridium cross-cut by an interlocking network of tulameenite veins. The tulameenite is greyish white, relative to platiniridium, and is slightly darker greyish white than the Pt-Fe alloy. It has a reflectivity of 44.6%, at 547 nm, and has a Vickers microindentation hardness of 633 $\pm$ 44 kg/sq. mm, for an applied load of 50 g. These values do not agree with those reported by Cabri *et al.* (1973), being lower and higher respectively. This may be due to the reduced Pt and increased Ir and Os content of this particular sample.

The tulameenite and platiniridium of Grain f are both characterized by intergrowths of one within the other (see Plate XII-2). This texture, plus their gross relationships tends to imply that this particular grain is a product of a possible exsolution of a tulameenite-platiniridium solid solution (Cameron, 1961).

Minor minerals which were encountered in the tulameenite, but not in the platiniridium, are $PtAu_4Cu_5$, RhSb and (Rh,Ir)SbS (see Plate XII-3).

Platiniridium, rather than the Pt-Fe alloy, is the dominant mineral in Grains e and f. It is white in colour, isotropic and non-bireflectant with a polishing hardness greater than tulameenite and the Pt-Fe alloy. Reflectivity (at 547 nm) is 70.4%. The Vickers

microindentation hardness varies from 533 ± 23 kg/sq. mm, for Grain e, to 642 ± 38 kg/sq. mm for Grain f, for an applied load of 50 g. Grain e consists of platiniridium with a number of small, discreet grains and veinlets of Pt-Fe alloy. This Pt-Fe alloy is also found either totally enclosing or rimming chromite inclusions within the platiniridium. Laurite, as orientated exsolution blebs (see Plate XII-4) is also present.

(b) Minor Platinoid Minerals

Osmiridium occurs exclusively as usually rounded inclusions, up to approximately 50 μ long but usually about 5 μ or less, within the Pt-Fe alloys. In one isolated case it occurs as a criss-cross network of acicular crystals with intersertal laurite (see Plate XII-5). Relative to Pt-Fe alloy it is yellowish white and has a higher polishing hardness. It is nonbireflectant and isotropic. Vickers microindentation hardness, for a 50 g load, is 531 ± 75 kg/sq. mm. No reflectance determinations were made, due to the small size of the inclusions.

Iridosmine is rarely present. It occurs as tiny, lath-like inclusions, up to approximately 14 μ long, within the Pt-Fe alloys, either singly or in clusters (see Plate XII-1). Iridosmine is bluish white in colour with no bireflectance or anisotropy. Its polishing hardness is greater than both the Pt-Fe alloys and the osmiridium.

Laurite is present in all but one of the grains studied. It is usually found as small (50 μ or less), anhedral inclusions, rarely as subhedral inclusions, as intersertal infillings, as exsolution blebs and as coatings along the margins of chromite inclusions (see Plates XII-4,5,6,7). Relative to Pt-Fe alloy it is bluish grey

in colour with no bireflectance and is isotropic. Its reflectivity, at 547 nm, is 42.2%, which is in close agreement with reported values for this wavelength (Uytenbogaadt and Burke, 1971).

(Ir,Rh)SbS is relatively rare being present in only two of the platinoid grains. It is quite similar to laurite in colour, being grey with a slight violet tinge under low power. This violet tinge is lost under higher powers due to chromatic aberrations, and it is then indistinguishable from laurite, even when both are in contact. (Ir,Rh)SbS, when present, occurs as small (less than 50 μ), discreet grains or as abundant inclusions forming coatings on chromite and laurite inclusions, primarily near the margin of the grain. This mineral shows a wide range of compositions resulting from different proportions of Ir and Rh. Raicevic and Cabri (1976) noted the presence of IrSbS and RhSbS in platinoid grains from the Tulameen district. It would therefore appear that what is present are members of an IrSbS-RhSbS solid solution series. Compositional data for this and the other platinoid minerals are given in Table V.

$PtAu_4Cu_5$ is found exclusively within the tulameenite of Grain f, usually as long, anhedral inclusions up to about 100 μ long. It has a light orange-pink colour, is nonbireflectant and isotropic. Its polishing hardness is much less than that of tulameenite and platiniridium. Occasionally inclusions of RhSb are present (see Plate XII-3).

RhSb is, like $PtAu_4Cu_5$, restricted to the tulameenite found in Grain f. It occurs as rare, small (less than 8 μ), brownish grey inclusions and is weakly anisotropic with no observable bireflectance. Its polishing hardness is approximately the same as tulameenite.

Pyrrhotite and chalcocite were very rarely seen, being present in Grain 'a' as several isolated inclusions that are less than 30 μ in size. They are both brown in colour with chalcocite being slightly darker (Plate XII-8). No bireflectance or anisotropy was observed.

Several sulphosalts, analogous to braggite, were identified in three of the grains studied. In all cases they occurred as rare xenomorphic inclusions within Pt-Fe alloy and in tulameenite (Plates XII 3 and 8). These grains, up to 40 μ in size, are distinctly bi-reflectant (bluish grey to brownish grey) and are anisotropic from grey to dark greyish brown. The optical properties observed are quite similar to those of braggite (Uytenbogaardt and Burke, 1971) though the minerals differ compositionally in that Ir and Rh are the dominant platinoid metals rather than Pt and Pd. Other common elements found within these minerals, in decreasing relative abundance, are Fe, Ni and Cu.

## 4.5 MICROPROBE STUDIES

Ten gold and seven PGE nuggets were analysed using electron microprobe techniques. Initially the samples were studied using Energy Dispersive Analysis (EDA), in order to obtain complete X-ray spectra for the minerals (see Fig. 4-6 and Fig. 4-7). Elemental identifications and cursory mineral diagnoses, based upon these spectra, were then performed.

The gold samples were found to consist of an alloy of gold and silver, although copper in quantities of less than 1% may have been

present in a few cases. The gold and silver content of these particular samples were then determined using quantitative Wavelength Dispersive Analysis (WDA). Operating conditions and standards used are given in Appendix 1a.

The PGE samples were found to consist of a number of platinoid and non-platinoid minerals in which a total of 12 elements were identified and determined. Operating conditions and standards used are given in Appendix 1b.

The data generated were subjected to a data reduction routine involving first reduction of the raw counts to counts per second. Then average background values were subtracted and a manual drift correction, based upon changes in the aperture current-probe current ratio, was applied. These adjusted raw data were then processed using the COR2 program (Henoc, *et al.*, 1973) for the gold analyses and the EDATA2 program (Gold, C. and Smith, D.G.W., in preparation) for the platinoid mineral analyses. A summary of the results, expressed in weight percent, is given in Table IV and Table V.

In the case of the PGE minerals it was found that major errors existed for many of the analyses to the extent that a variation of approximately 60% between extremes was encountered. Only a third of the analyses were found to be within acceptable limits. It is believed that these errors, which showed no definite pattern, are the product of several transitory and intrinsic errors characteristic of these particular analytical conditions.

Plant (1976) has noted that:

Table IV

Compositions of Ten Gold Nuggets from the Swan Prospect

| Sample # | Au | Ag | Total (wt. %) |
|---|---|---|---|
| GC 1 | 85.80 | 13.86 | 99.66 |
| GC 2 | 89.40 | 9.74 | 99.14 |
| GC 3 | 91.15 | 8.02 | 99.17 |
| GC 4 | 89.78 | 9.26 | 99.04 |
| GC 5 | 89.31 | 9.72 | 99.02 |
| GC 6 | 89.05 | 9.56 | 98.61 |
| GC 7 | 89.47 | 8.71 | 98.18 |
| GC 8 | 94.72 | 4.14 | 98.86 |
| GC 9 | 94.47 | 4.18 | 98.64 |
| GC 10 | 89.80 | 9.51 | 99.31 |

Table V

Composition of Thirteen Selected PGE Alloys and Minerals Found in the Swan Prospect PGE Nuggets Studied.

| | S | Fe | Ni | Cu | As | Ru | Rh | Sb | Os | Ir | Pt | Au | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| a) | 0.07 | 16.63 | 0.93 | 0.79 | 0.00 | 0.03 | 1.15 | n.d. | 0.14 | 8.23 | 70.91 | n.d. | 98.88 |
| b) | 0.04 | 12.42 | 1.23 | 0.51 | 0.00 | 0.02 | 0.78 | n.d. | 0.18 | 18.45 | 66.39 | n.d. | 100.02 |
| c) | 0.07 | 11.27 | 1.37 | 8.65 | 0.00 | 0.00 | 0.71 | n.d. | 5.45 | 2.81 | 68.86 | n.d. | 99.19 |
| d) | 0.00 | 1.70 | 0.06 | 0.89 | 0.00 | 1.45 | 0.80 | n.d. | 3.21 | 79.23 | 14.33 | n.d. | 101.67 |
| e) | 0.00 | 3.08 | 0.04 | 0.62 | 0.00 | 0.62 | 2.39 | n.d. | 23.62 | 64.01 | 7.19 | n.d. | 101.57 |
| f) | 0.00 | 0.37 | 0.00 | 0.60 | 0.00 | 0.73 | 2.28 | n.d. | 23.69 | 61.41 | 11.93 | n.d. | 101.01 |
| g) | 0.00 | 1.33 | 0.00 | 0.36 | 0.00 | 0.44 | 0.85 | n.d. | 55.54 | 42.45 | 0.95 | n.d. | 101.92 |
| h) | 37.98 | 0.03 | 0.01 | 0.04 | 1.27 | 55.03 | 0.23 | n.d. | 3.43 | 6.42 | 0.08 | n.d. | 104.52 |
| i) | 9.95 | 0.09 | 0.00 | 0.34 | 0.00 | 0.00 | 23.93 | 40.73 | 0.49 | 26.40 | 1.50 | 0.00 | 103.43 |
| j) | 9.01 | 0.35 | 0.00 | 0.49 | 0.00 | 0.02 | 2.89 | 35.07 | 0.04 | 49.47 | 1.85 | 0.00 | 99.19 |
| k) | 0.02 | 0.29 | 0.06 | 23.51 | 0.00 | 0.00 | 0.02 | 0.00 | 0.07 | 0.00 | 15.80 | 58.45 | 98.22 |
| l) | 0.02 | 0.06 | 0.01 | 0.30 | 0.00 | 0.00 | 44.36 | 51.29 | 0.01 | 1.32 | 1.06 | 0.00 | 98.43 |
| m) | 30.07 | 16.83 | 9.96 | 5.78 | 0.00 | 0.04 | 20.95 | n.d. | 0.15 | 18.20 | 1.24 | n.d. | 103.22 |

a) Pt-Fe alloy
b) Pt-Fe alloy
c) Tulameenite
d) Platiniridium
e) Osmiridium
f) Osmiridium
g) Iridosmine
h) Laurite
i) (Ir,Rh)SbS
j) (Ir,Rh)SbS
k) $PtAu_4Cu_5$
l) RhSb
m) $(Fe_{0.32}Rh_{0.22}Ni_{0.18}Ir_{0.10}Cu_{0.10})_{0.92}S$

n.d. - not determined

> "For the accurate analysis of minerals of high average atomic number, eg. ... minerals of the platinum-group elements, several authors have stressed the use of synthetic standards close in composition to the unknown, rather than pure metals ... Such a procedure will minimize errors due to uncertain background values for some element combinations ... and to incorrect mass absorption coefficients".

In the case of these particular analyses pure element standards only were available for most of the elements sought.

Since, in most cases, elemental concentrations were much lower in the samples than in the standards, it must be assumed that errors exist in background values and in the use of incorrect compound mass absorption coefficients.

With the platinum-iron alloys (of which a total of 8 sample locations were analysed) another factor exists that significantly affects the total error. This is due to the fact that Pt-Fe alloys often consist of two intimately associated principal alloys: 'platinum' and 'osmiridium'. It is commonplace for very minute exsolution domains of one alloy, of micron dimentions, to be present in the other (Mertie, 1969). Such is the case for the Granite Creek samples in which osmiridium frequently occurs as micro inclusions within the Pt-Fe alloy. Many of these inclusions are too small to be resolved by the optic system found on the ARL EMX microprobe. Thus, though no inclusions may have been evident, in fact the beam excitation area may have included, at least in part, some domains of osmiridium and so contributed to, or effectively reduced the X-ray intensity for several of the elements determined.

Potentially the most significant error was that contributed

by operator error. This consists primarily of failure to detect inconsistancies in crucial instrument settings such as beam spot location, flipping of the various spectrometer crystals and adjustments of wavelength settings. Of these beam spot wander is assumed to be responsible for several anomalous totals. This is due primarily to the extremely small size of a number of the mineral phases analysed. In such cases movement of the spot as much as several microns would have resulted in the analysis of the matrix rather than the inclusion intended for study.

# CHAPTER FIVE

## SUMMARY AND CONCLUSIONS

The Swan prospect consists of Au-PGE-bearing gravels within a portion of a Tertiary (?) paleochannel that was perserved by a mantle of fluvial-glacial material. It has been found that this particular deposit does not represent a primary placer accumalation, but rather is the product of reworking of older deposits. Based on the pervasive joint system of the area and the known source of the PGE metals it is believed that other portions of this particular paleochannel and/or the remnants of the previous placer(s) from which it was derived can be found to the west of Granite Creek in the vicinity of Arrastra, Newton and Blakeburn Creeks. The use of air photographs, at a scale of approximately 1 : 5000 should prove to be a definite asset in the search for paleochannels in the area.

The PGE alloys and minerals present in this deposit are of special interest being, in several cases, unique to this area. Further work on these in order to determine crystal structures and chemistry should produce sufficient data based upon which these alloys and minerals can then be named. It is expected that during such studies other, previously undiscovered minerals, will be found. Therefore, an effort should be made to preserve samples for scientific use while at the same time develop what may prove to be a profitable market.

At present the deposit has yet to be blocked out and accurate assays made. Based on what is known from underground development, seismic results and air photo interpretation there is a minimum 16,000 cubic yards in potential reserves, probably with an average tenor of

at least 0.15 oz. Au and 0.03 oz. PGE per cubic yard and with a minimum gross value of about $1 million. The initiation of full-scale sampling of this deposit should increase potential reserves and tenor significantly. Thus this small deposit, with proper financing and management may yet prove to be a large producer.

This study has in particular shown the usefullness of air photographs and seismic surveying in delineating buried placers. Application of these methods to the target areas previously mentioned should prove profitable.

REFERENCES

British Columbia Department of Mines - Annual Report: 1902

British Columbia Department of Mines - Annual Report: 1915

British Columbia Department of Mines - Annual Report: 1923

British Columbia Department of Mines - Annual Report: 1925

British Columbia Department of Mines - Annual Report: 1934

Butterman, W.C. (1975): Platinum-group metals; *In* Mineral Facts and Problems; U.S. Bureau of Mines, Bull. 667, pp 835-854.

Cabri, L.J. and Feather, C.E. (1975): Platinum-iron alloys: a nomenclature based on a study of natural and synthetic alloys; *Can. Mineral., Vol. 13, pp 117-126.*

Cabri, L.J., Owens, D.R. and Laflamme, J.H.G. (1973): Tulameenite, a new platinum-iron-copper mineral from placers in the Tulameen River area, British Columbia; *Can. Mineral., Vol. 12, pp 21-25.*

Cameron, E.N. (1961): Ore Microscopy; John Wiley and Sons, Inc., New York.

Camsell, C. (1913): Geology, and Mineral Deposits of the Tulameen District, B.C.;*Can. Geol. Surv., Mem. 26, 188 p.*

Carr, J.M. (1962): Geology of the Princeton, Merritt, Kamloops area of southern British Columbia; *Western Miner, Vol. 35, pp 46-49.*

Dawson, G.M. (1877a): Report on explorations in British Columbia; *Can., Geol. Surv., Rept. of Prog. 1875-76, pp 233-265.*

Dawson, G.M. (1877b): The mineral wealth of British Columbia; *Can., Geol. Surv., Ann. Rept., Vol. 3, pt. R, pp 1-163.*

Dennis, J.G. (1972): Structural Geology; Ronald Press Co., New York, p. 290.

Eales, H.V. (1967): Reflectivity of gold and gold-silver alloys; *Econ. Geol., Vol. 62, pp 412-420.*

Engineering and Mining Journal, August, 1978.

Findlay, D.C. (1969): Origin of the Tulameen ultramafic-gabbro complex, southern British Columbia; *Can. J. Earth Sci., Vol. 6, pp 399-425.*

Findlay, D.C. (1963): Petrology of the Tulameen ultramafic complex, Yale District, B.C.; Unpub. Ph.D. Thesis, Queen's University.

Fulton, R.J. (1975): Quaternary Geology and Geomorphology, Nicola-Vernon Area, British Columbia; Can. Geol. Surv., Mem. 380, 50 p.

Findlay, D.C. (1963): Petrology of the Tulameen ultramafic complex, Yale District, B.C.; Unpub. Ph.D. Thesis, Queen's University.

Galloway, J.D. (1931): Placer Mining in British Columbia; B.C. Dept. of Mines, Bull. No. 1.

Henoc, J., Heinrich, K.F.J. and Myklebust, R.L. (1973): A rigorous correction procedure for quantitative electron probe micro-analysis (COR 2); U.S. Dept. of Commerce, N.B.S. Technical Note 769, 127 p.

Hills, L.V. (1962): Glaciatian, stratigraphy, structure and micro-paleobotany of the Princeton Coalfield, B.C.; Unpub. M.Sc. Thesis, University of British Columbia.

Holland, S.S. (1964): Landforms of British Columbia: a physiographic outline; B.C. Dept. of Mines and Petro. Res., Bull. 48

Jackson, E.D. and Thayer, T.P. (1972): Some criteria for distinguishing between stratiform, concentric and alpine peridotite-gabbro complexes; *In* "IGCI, Twenty-forth session, section 2", pg. 289.

Kemp, J.F. (1902): The geological relations and distribution of platinum and associated metals; U.S. Geol. Surv., Bull. 193.

McGowan, J.H. (1978): Alluvial fan systems; *In* "Depositional and ground-water flow systems in the exploration for uranium - a research collequium"; Bureau of Econ. Geol., University of Texas, Austin, Texas.

Mertie, J.B., Jr. (1969): Economic Geology of the Platinum Metals; U.S. Geol. Surv., Prof. paper 630.

Naldrett, A.J. and Cabri, L.J. (1976): Ultramafic and related mafic rocks: their classification and genesis with special reference to the concentration of nickel sulphides and platinum-group elements; *Econ. Geol., Vol. 71, pp 1131-1158.*

*Northern Miner, Vol. 64, No. 30, 1978*

Pettijohn, F.J. (1949): Sedimentary Rocks; Harper and Brothers, New York.

Plant, A.G. (1976): Applications of microbeam techniques to mineralogy; *In* Min. Assoc. Can., "Short Course in Microbeam Techniques" (D.G.W. Smith, ed.), pp 107-134.

Poitevin, E. (1923): Platiniferous rocks from Tulameen map-area, Yale district, British Columbia and Ural Mountains, Russia; *Can. Geol. Surv., Sum. Rept., Pt. A, pp 84-101.*

Preto, V.A. (1977): The Nicola Group: Mesozoic volcanism related to rifting in southern British Columbia; *In* "Volcanic Regimes in Canada"; Geol. Assoc. of Can., Spec. Paper No. 16 (W.R.A. Barager, L.C. Coleman and J.M. Hall, eds.), pp 39-57.

Raicevic, D. and Cabri, L.J. (1976): Mineralogy and concentration of Au- and Pt-bearing placers from the Tulameen River area in British Columbia; *Can. Inst. Min. Met. Bulletin, pp 1-9.*

Rice, H.M.A. (1947): Geology and Mineral Deposits of the Princeton Map-Area, B.C.; *Geol. Surv., Memoir 243, 136 p.*

Schau, M. (1968): Geology of the Upper Triassic Nicola Group in South-central B.C.; Unpub. Ph.D. thesis, University of British Columbia.

Schumm, S.A. (1972): Fluvial paleochannels; *In* "Recognition of Ancient Sedimentary Environments (J.K. Rigby and W.K. Hamblin, eds.). Soc. of Econ. Paleon. and Min., Spec. Pub. No. 16, pp 98-107.

Schumm, S.A. (1968): Speculations concerning paleohydrologic controls of terrestrial sedimentation; *Geol. Soc. Am. Bull., Vol. 79, pp 1573-1588.*

Schumm, S.A. (1960): The effect of sediment type on the shape and stratification of some modern fluvial deposits; *Am. J. Sci., Vol. 258, pp 177-184.*

Stanton, R.L. (1972): Ore Petrology; McGraw-Hill Book Co., New York, pp 306-326.

Tourtelot, H.A. and Riley, L.B. (1973): Size and shape of gold and platinum grains; *In* "Ores in Sediments", IUGS Series A, No. 3 (G.C. Amstertz and A.J. Bernard, eds.), Springer-Verlag, Berlin, pp 307-319.

Uytenbogaardt, W. and Burke, E.A.J. (1971): Tables for Microscopic Identification of Ore Minerals; Elsevier Publishing Co., Amsterdam, p. 330.

Wells, J.H. (1973): Placer Examination-Principles and Practice: U.S. Dept. of the Interior, Technical Bulletin 4, 209 p.

Appendix 1a

Summary of Operating Conditions and Standards Used

In the Electron Microprobe Analyses of Gold Nuggets

| Element | Peak | Detector Crystal | Crank Setting | Background | Operating Voltage | Standard | Comments | CCN |
|---|---|---|---|---|---|---|---|---|
| Au | $M_{\alpha}$ | $LIF_1$ | 1.2620 | 1.3120<br>1.2120 | 20 kv | EPS 18-2 | 100% Au | 126 |
| Ag | $L_{\alpha}$ | $PET_2$ | 1.9114 | 1.9614<br>1.8614 | 20 kv | EPS 9-2 | 100% Ag | 284 |

Instrument Used: Applied Research Laboratories EMX Electron Microprobe

Appendix 1b

Summary of Operating Conditions and Standards Used in the

Electron Microprobe Analyses of the PGE Alloys and Minerals

| Element | Peak | Detector Crystal | Crank Setting | Background | Operating Voltage | Standard | Comments | CCN |
|---|---|---|---|---|---|---|---|---|
| S | Kα | $ADP_1$ | 2.0355 | 2.0855<br>1.9855 | 15 kv | EPS 28-7 | PdS | 259 |
| Fe | Kα | $LlF_2$ | 1.9335 | 1.9835<br>1.8835 | 20 kv | EPS 28-14 | PtFe | 233 |
| Ni | Kα | $LlF_2$ | 1.6563 | 1.7063<br>1.6063 | 20 kv | EPS 4-14 | 100% Ni | 201 |
| Cu | Kα | $LlF_1$ | 1.5337 | 1.5837<br>1.4837 | 20 kv | EPS 4-1 | 100% Cu | 069 |
| As | Lα | $TAP_3$ | 1.5139 | 1.5638<br>1.4450 | 20 kv | EPS 28-12 | $Pd_8As_3$ | 258 |
| Ru | Lα | $ADP_1$ | 1.8500 | 1.8850<br>1.7850 | 15 kv | Ru Std | 100% Ru | 274 |
| Rh | Lα | $PET_2$ | 2.1150 | 2.1650<br>2.0650 | 15 kv | Rh Std | 100% Rh | 273 |

continued on next page

Appendix 1b continued

| Element | Peak | Detector Crystal | Crank Setting | Background | Operating Voltage | Standard | Comments | CCN |
|---|---|---|---|---|---|---|---|---|
| Sb | Lα | $PET_2$ | 1.5843 | 1.6343<br>1.5343 | 20 kv | EPS 18-3 | $Sb_2S_3$ | 295 |
| Os | Mα | $PET_2$ | 2.9823 | 3.0323<br>2.9323 | 20 kv | Os Std | 100% Os | 230 |
| Ir | Lα | $LIF_1$ | 1.3375 | 1.4500<br>1.2875 | 20 kv | Ir Std | 100% Ir | 158 |
| Pt | Lα | $LIF_1$ | 1.3000 | 1.4300<br>1.7500 | 20 kv | EPS 28-14 | PtFe | 233 |
| Au | Lα | $LIF_1$ | 1.2620 | 1.3120<br>1.2120 | 20 kv | EPS 18-12 | 100% Au | 126 |

Instrument used: Applied Research Laboratories EMX Electron Microprobe